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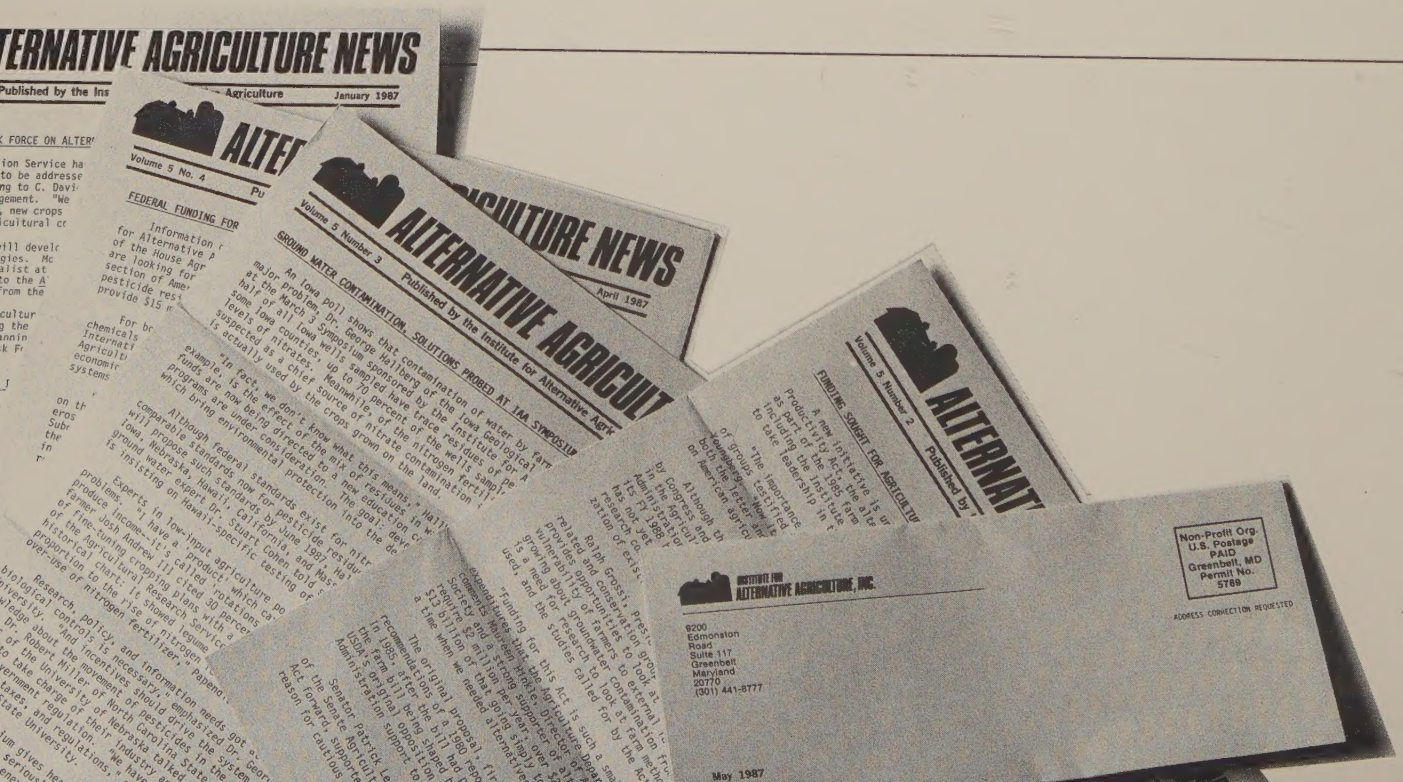
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Institute Information

The Institute for Alternative Agriculture is a nonprofit, tax-exempt research and education organization established in 1983 to encourage and facilitate the adoption of low-cost, resource-conserving and environmentally-sound farming methods. It works closely with producer groups, public research and education institutions, and government agencies in promoting a sustainable agriculture system.

Its programs include providing a national information clearinghouse, serving as a voice for sustainable agriculture in Washington, and developing and implementing research and educational outreach programs. It holds an annual scientific symposium and publishes a monthly newsletter.

The Institute is governed by a grass roots Board of Directors, which includes several commercial-scale organic farmers, and maintains a small professional staff. It is supported by memberships and donations and grants from foundations, corporations, and individuals.

Cover Photo

Pictured are research plots near Ithaca, New York, in which sweet corn is inter-cropped with white clover living mulch. The clover protects and improves the soil, but must be suppressed to avoid interference and reduced corn yield. Multiple corn row arrangements (foreground) make it easier to impose various mechanical suppression treatments on the clover. Photo provided by Vernon P. Grubinger, University of Vermont Extension Service, West Brattleboro, Vermont.

FROM THE EDITOR

With this issue, we begin publication of the fifth volume of the *American Journal of Alternative Agriculture (AJAA)*. From the outset, we have always sought to maintain the highest possible professional and scientific standards, and we will continue to do so in the future. The success, to date, of the *AJAA* stems to a very large degree from the dedication of those professionals listed below who have so generously given of their time and energy in serving as anonymous reviewers. On behalf of our editorial staff, I want to acknowledge and sincerely thank them for responding so promptly and thoroughly to our requests to review manuscripts. As we contemplate the future, it is reassuring to know that these and other future reviewers stand ready to contribute in this critically important way to the furtherance of the scientific basis of alternative agriculture.

I. Garth Youngberg, Editor

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Types of articles in the American Journal of Alternative Agriculture

As we enter our fifth year, it is very gratifying to see th number of manuscripts we receive continuing to increase rap idly. With this increase has come greater diversity in the topic covered and the backgrounds and affiliations of the authors

This, too, is very gratifying because we have always intended the journal to cover alternative agriculture in its broadest sense.

One small difficulty that this growth and diversification have created is that manuscripts do not always fall into any of our categories of articles. In part, this problem may have arisen because some articles in early issues of the journal give a slightly mistaken impression of what each category is supposed to be. Therefore, we would like to clarify what we have in mind for each type of article. A manuscript that clearly fits one of these descriptions can be processed much more quickly and is more likely to be accepted for publication.

Articles: These are the full-length articles not qualified by any other label (e.g., "commentary") that make up the main body of every issue. They fall into three classes:

1. Research articles. Reports of original research are similar to those found in standard research journals. They are all subjected to peer review, with the customary standards applying: relevance, originality, significance, validity, and clarity. One additional criterion not always applicable to other journals is that an article for the *American Journal of Alternative Agriculture* (*AJAA*) should be understandable to readers with a wide range of backgrounds, not just people in the authors' specialty.

2. Review articles. This, too, is a familiar category, although in many fields, reviews are not nearly as common as they deserve to be. We would like to correct that, and we encourage you to submit a review on any subject relevant to the *AJAA*.

3. Preliminary reports on highly innovative systems. This is a category that is not found in some journals but which we consider appropriate for alternative agriculture. It covers areas about which very little research has been done by anyone, but which promise to be very attractive. The data presented in such an article can be less complete than in a conventional research report. The point is to make people aware of a concept or approach that there is some basis for being encouraged about, even though it clearly needs much more work. Articles of this kind have been infrequent in the *AJAA*; the recent one by Schroeder and Serfling (1989) is a good example of what we would like to see in this type of article.

Note that such an article is *not* the same as a report on work in progress on a much more familiar topic, for which you should simply wait for the research to be finished and then present a full account. The question is: Has *anyone* ever carried work of this kind any further? If so, your paper should meet customary standards for adequacy of the data. But if the answer is "no," the manuscript *might* be a candidate for this type of article, if it deals with a highly innovative and promising concept.

Opinions: These are short pieces that take a stand on a current policy issue. Usually an opinion article makes just one main point so it can argue the case convincingly in about one journal page.

We have been receiving many good opinion submissions recently, but we plan to continue publishing only one per journal issue. Because we would like to deal with the full range of relevant subjects, we will give priority to opinion articles in areas that have not already received substantial coverage in this department.

Commentaries: These fall between opinion pieces and regular articles. Like the former, they may deal with controversial issues. However, they should do so in a more thorough and a more analytical way, and their length can be whatever is appropriate to do justice to the subject. Similarly, commentaries usually have a full list of references, whereas citations in opinion articles are optional. The purpose of a commentary is not so much to argue a particular position as to stimulate thinking and discussion. However, a commentary article can take a particular stand (in a reasoned and thoughtful manner, of course).

Alternative Agriculture Profiles: These are descriptions of working farms on which innovative systems are being tried. A farm profile usually will not have the same depth of data as a conventional research article. However, it should be supported by at least some data collected either by the author or a third party; purely anecdotal accounts or farmer testimonials will generally not be adequate.

We would like to make these profiles a regular feature of the *AJAA* and strongly encourage submissions. The only one we have had so far (Gage and Smith, 1989) is an excellent example of what we have in mind. Further explanation can be found in Vol. 3, No. 4, p. 188.

A final note. Some authors submit material that is not yet in the form of a conventional manuscript to get a preliminary opinion on whether it might be acceptable as an article. This material might be a lengthy technical report that could be condensed into a research article, or the text of a speech that could be edited into an opinion piece, or the charts from a poster session for which a text could be supplied.

We understand why authors would like a preliminary opinion on something that is already at hand before putting in the effort necessary to produce a regular manuscript. Until now we have honored such requests. However, this entails much more work than reviewing something in proper manuscript form. Because we now are getting many more submissions, but have not increased our staff nearly as much, we simply cannot continue to deal with material in non-standard format, much as we would like to. Consequently, we will only accept formal submissions in one of the categories described above. Simply stated, a manuscript should look like a manuscript; if it doesn't, we will return it without judging its merits. We trust you understand the need for this policy; without it, the available staff time would be spread too thin to give each manuscript the attention that it must get if we are to uphold the quality of the *AJAA*.

Moving a manuscript from submission to publication can be a difficult process, even under the best of circumstances. Fortunately, without exception our authors have been extremely cooperative. We hope that our explanations of what we look for in each type of article will help this process go even more smoothly.

William Lockeretz, Technical Editor

Gage, Susan, and Stewart Smith. 1989. Farm profiles: The Moore dairy farm. American Journal of Alternative Agriculture 4(1):35-37.

Schroeder, Gerald L., and Steven Serfling. 1989. High-yield aquaculture using low-cost feed and waste recycling methods. American Journal of Alternative Agriculture 4(2):71-74.

Managing white clover living mulch for sweet corn production with partial rototilling

Vernon P. Grubinger and Peter L. Minotti

Abstract. *Living mulch is a cover crop which is intercropped with a cash crop to protect against soil erosion and structural deterioration without taking land out of production. To avoid interference which reduces cash crop yield, the mulch requires management techniques which minimize resource utilization during the critical period of crop development without killing the mulch outright. The experiments reported here examine non-chemical management innovations in a sweet corn-white clover intercrop system which allow for clover regrowth and also contribute to the N requirement of the corn. In 1986 clover was suppressed by mowing or partial rototilling. Yields of corn in plots where clover was rototilled were comparable to yields of clean cultivated corn and superior to yields from plots where clover was mowed or unsuppressed. In 1987 rototilling was compared at 3 timings after corn emergence. Highest corn yields were obtained by rototilling the well-established clover at 2 rather than 4 or 6 weeks after emergence. Yields from rototilled plots in 1987 exceeded those from clean cultivated plots or plots where clover was unsuppressed. After rototilling, the clover reestablished via stoloniferous growth emanating from a narrow strip of roots which passed between the tiller tines. In both years corn leaf N concentrations were highest in the rototilled plots. In 1987 clean cultivated corn appeared N deficient and had a greater incidence of corn smut than corn from the rototilled clover plots. Multiple corn row arrangements which facilitate access to the mulch were compared at a constant plant population to conventional single rows on 76 cm centers. There were no differences in yield between single and double rows (152 cm centers) in either year, while the triple-row arrangement (228 cm centers) reduced yield in 1987 due to the low productivity of the plants in the middle row of the 3 rows.*

Key words: intercropping, fertilizer nitrogen, green manure, row arrangement, cover crops, corn smut

Introduction

Long-term maintenance of soils is particularly difficult with intensive crop production by specialized growers who do not rotate their fields with soil-improving crops. Some very productive soils in New York have deteriorated, at times rapidly, over the last 50 years due to a combination of factors including erosion, continuous cash cropping, deep plowing, and compaction (Peck, 1988). Greater use of cover crops and green manures in rotation would likely have helped the situation, but short-term economic incentives against taking land out of cash crops are strong. One alternative to conventional cultivation is living mulch, a cover crop maintained as a perennial intercrop between a row crop, providing some year-round ground cover which protects against erosion and mitigates against a decline in soil structure and fertility without taking land out of production (Minotti and Sweet, 1981). A leguminous living mulch may add symbiotically fixed N as well as organic matter to the soil. Unlike no-till agriculture, in which the ground cover is completely killed with herbicide to reduce its competitiveness, living mulch should be non-lethally suppressed to allow regrowth of the ground cover. Ideally, suppression should occur only during the critical growth period of the cash crop, when interspecific competition will reduce yield; growth and N fixation by the leguminous mulch is desirable at other times. Strip-tillage of the mulch to prepare planting strips for the row crop and plow-down of the remaining mulch after several years may improve soil aggregate stability and bulk density, although the effects of green manuring depend upon edaphic and climatic conditions and plant species (Pieters, 1927; MacRae and Mehuys, 1985).

To avoid cash crop yield reductions, the living mulch must be suppressed to reduce interference. For example, without suppression, a white clover living mulch reduced the yield of sweet corn (Nicholson and Wien, 1983; Vrabel, 1981, 1983; Peters, 1986) and cabbage (Nicholson and Wien, 1983; Wyland, 1986). On the other hand, the use of intercropped forages in corn production has generally been successful when the sods were chemically suppressed (Adams et al., 1970; Bennett et al., 1976; Box et al., 1980; Elkins et al., 1979; Hartwig, 1974). In New York, Vrabel (1981, 1983) showed that sweet corn intercropped with white clover suppressed by atrazine (6-chloro-N-ethyl-N′-(1-methylethyl)-1,3,5-triazine-2,4-diamine) yielded as well or better than clean cultivated corn, depending on the year. In one of his experiments, corn in the atrazine-regulated mulch which received 17 kg N ha^{-1} in the starter band yielded as well as clean cultivated corn which received an additional 67 kg N ha^{-1} as a sidedress. Approximately half of the clo-

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ver stand had been incorporated into the planting strip just prior to corn seeding. Corn leaf N concentrations were also increased by intercropping with the atrazine-suppressed clover mulch. In a similar system using an atrazine-suppressed white clover mulch, Peters (1986) showed that the yield advantage with the clover mulch versus clean cultivation was greatest without the addition of N fertilizer. Thus, it appears that careful management of a clover intercrop could reduce the fertilizer N requirement of corn as well as protect the soil.

The use of living mulch is risky, however, without adequate rainfall or irrigation. Vrabel (1983) showed that, during an extended dry period, corn from unirrigated clover mulch plots yielded less than corn from unirrigated bare ground control plots despite suppression of the mulch with atrazine.

One problem with atrazine suppression is that the effect of a given dosage on the clover will vary according to the stage of clover growth and environmental conditions. Thus, a rate successful one year was found to be too drastic in another year (Vrabel, 1983). Moreover, many of the growers expressing an interest in living mulch systems prefer low-chemical management options. For these reasons we decided to more fully examine the feasibility of mechanical suppression of white clover living mulch.

Materials and methods

Plots were established in 1986 at the H. C. Thompson Vegetable Research Farm in Freeville, New York, on a Howard gravelly loam soil (loamy-skeletal, mixed mesic, Glossoboric Hapludalf). A composite soil sample taken on 18 April 1986 had a pH of 6.0 and contained 2.8 percent organic matter based on a 1:1 soil-water suspension and loss on ignition from dried soil, respectively. Available nutrient levels were determined by atomic absorption after extraction with Morgan's sodium acetate-acetic acid solution buffered to pH 4.8 (Greweling and Peech, 1965), with the exception of P, which was determined colorimetrically by stannous chloride reduction. Available P and K levels were in the high range for vegetable production on mineral soils. There were 18, 132, 61 and 1059 mg kg^{-1} of available P, K, Mg and Ca, respectively. Soil bulk density was 1.1 g cm^{-3} based on the weight of 10 cc of unpacked soil dried at 50 C and passed through a 2 mm screen. CEC was 13.5 meq 100 g^{-1} as determined with neutral 1 N ammonium acetate. The soil was very gravelly, with poor structure and a plow pan at a depth of about 20 cm.

On 22 April 1986, calcite at 4.2 mt ha^{-1} and N, P and K at rates of 102, 45 and 85 kg ha^{-1} of N, P and K, respectively, were broadcast and the site was moldboard plowed and harrowed. In view of the high soil test for P and K, there was little chance of response to these nutrients, so fertilization of P and K at these rates is not recommended practice. It occurred due to the requirements of adjacent blocks of land and convenience factors. Dutch white clover (*Trifolium repens* L.) treated with clover inoculant (Agway, Inc.) was broadcast at the rate of 19 kg ha^{-1} on 29 April. A heavy seeding rate was utilized to promote early competition with annual weed seedlings and to ensure rapid establishment of a dense stand of clover. On 20 April 1987 the same quantities of calcite, P and K were applied as in the previous year. Nitrogen management was changed in 1987 so that 46 kg N ha^{-1} was topdressed, as NH_4NO_3, in the corn rows, split to provide 23 kg N ha^{-1} at planting and one month later.

On 4 June 1986, a 38 cm-wide planting strip was prepared for each corn row by shallow cultivation with a wheel-hoe which removed the dense but recently established clover. On 2 June 1987, 2 passes with a multivator (multiple unit rototiller) turned in the well-established clover to create 50 to 55 cm-wide planting strips for corn, intended to minimize interference from the well-established clover early in the season. Intercropping vegetables with narrow rather than wide strips of living mulch has been shown to lessen reductions in yield compared to clean cultivation (Altier and Wien, 1988; Loy et al., 1987; Vrabel, 1981). Within 3 days of planting strip preparation in both years, Jubilee sweet corn (*Zea mays* L.) was hand sown at a population of 53,400 fungicide-treated seeds ha^{-1}. At harvest, plant populations averaged about 49,000 plants ha^{-1} in both years, with no differences among treatments. An experimental unit consisted of 3 data rows 4.5 m long, bordered on each side by 2 or 3 corn rows planted in the same row arrangement.

The experiment was a randomized complete block design replicated 3 times, with 3 row arrangements and 5 suppression treatments in a factorial structure. Row arrangements consisted of single-, double- and triple-row groupings on 76, 152 and 228 cm centers, respectively (Figure 1). Corn rows within groupings were 38 cm apart. Suppression treatments included 2 controls: clean cultivation (clover absent) and unsuppressed clover. In 1986, the suppressed treatments were: clover mowed 2 or 5 times during the season or partially rototilled 6 weeks after corn emergence. In 1987, in order to better define the optimal timing of clover rototilling, clover was suppressed by rototilling 2, 4 or 6 weeks after corn emergence. The extent of clover ground

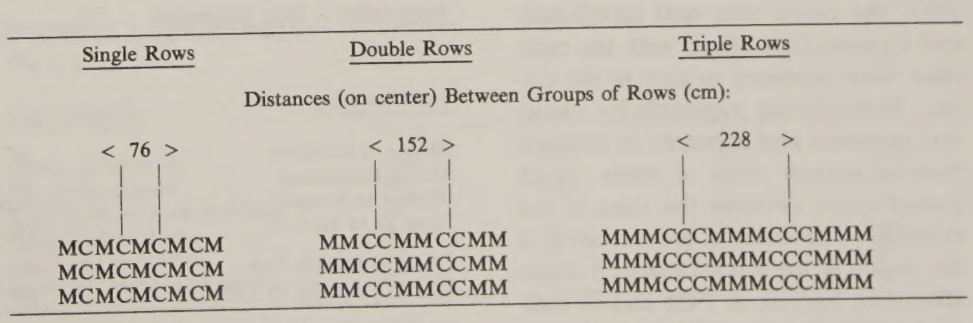

Figure 1 Schematic Representation of Row Arrangements of Sweet Corn (C) and White Clover Living Mulch (M) in 1986 and 1987 Experiments.

cover prior to corn planting in 1987 was similar among the intercrop plots, regardless of whether they were mowed or rototilled in 1986.

To eradicate weeds and invading clover in the clean cultivated plots, glyphosate (N-(phosphonomethyl)glycine) was applied as a 1 percent v/v and 2 percent v/v solution on 5 May and 27 May 1987 at the rate of 2.57 and 5.14 kg ha^{-1} a.i., respectively. Weeds throughout the clean cultivated plots and within corn rows in clover plots (19 cm to each side of the row) were hand cultivated 2 or 3 times until mid-July in both years. Randomization of row arrangement treatments precluded spraying of conventional herbicides within the corn rows although this is a feasible method of weed control with living mulch, as is mechanized row cultivation, when row arrangement is uniform throughout the field. Weeds growing above the clover canopy were removed by hand pulling in late June of 1986 to encourage establishment of a dense clover stand unhampered by competition from a few large weeds. A wiper application of systemic herbicide could provide similar weed control. Species uprooted at this time were primarily lambsquarters (*Chenopodium album* L.) and red-root pigweed (*Amaranthus retroflexus* L.). Overhead sprinkler irrigation was applied very infrequently, as rainfall was well distributed in both years. All plots were mowed after corn harvest in 1986 and before corn planting in 1987 to help control weeds in the clover.

In 1986, mowed clover treatments were cut to a height of 15 cm with a rotary mower and the clippings removed. The rototilling treatment was a single pass over the entire clover swath with an 8 hp pedestrian rototiller. In 1987, the clover was well established, and 2 passes (not offset) with the rototiller were necessary to turn in the clover. Stoloniferous regrowth by clover was extensive and appeared to emanate from a narrow strip of roots which passed intact between the tines of the rototiller. The extent of ground cover in the mulch strips was estimated 3 weeks after corn harvest in 1986 and in midwinter following the 1987 season by visual ratings in four 0.5 m^2 quadrats per plot. These data were arcsin transformed prior to analysis (Little, 1985).

Corn ears were harvested and unhusked fresh weight yields determined from 4 m of each of the 3 data rows per plot on 9 September 1986 and on 4 September 1987. Marketable ears were considered to be a minimum of 28 cm in length and 6 cm in width. Corn leaf samples were taken on 3 dates in 1986 and 4 dates in 1987 to monitor the relative nitrogen status of the plants. Samples were composites of ear leaves taken from 9 plants per experimental unit, except early in the season when ears were not yet present, in which case the uppermost fully expanded leaf was sampled. A majority of the corn plants reached the full silk stage during the third week of August in 1986 and during the second week of August in 1987, although the timing of plant development, including silking, varied among treatments and blocks. Leaf samples we dried at 70 C, ground through a 40-mes screen with a Wiley mill, and stored a 0 C. Total-N content was determined b a modified micro-Kjeldahl metho (Pomology Dept., Cornell Univ.) an NO_3-N content was determined, afte aqueous extraction, with an Orion sp cific ion electrode against a constar background of ionic strength. Analyse of variance were performed using th PROC GLM statement of SAS Versio 5.0 (SAS Institute, 1985).

Results and discussion

Corn yields

Despite the recent establishment c clover and the cultivation of 50 percen of the soil surface to create wide clover

Table 1. Sweet Corn Yields in 1986

	Unhusked Ear Fresh Weight, mt ha^{-1}		
	Total	Marketable[x]	Cull
Suppression Treatment:			
Clean Cultivated	7.65 ab[y]	5.44 a	2.22 b
Rototilled 7-21	8.80 a	5.56 a	3.24 a
Mowed 5 Times	6.60 bc	3.59 b	3.02 a
Mowed 2 Times	4.71 c	2.27 b	2.44 a
No Suppression	4.81 c	2.32 b	2.49 a
LSD (.05)	1.93	1.71	0.83
p > F[z]	.0004	.0003	.01
Row Arrangement:			
Single	6.61 a	3.80 a	2.81 a
Double	6.71 a	3.95 a	2.77 a
Triple	6.22 a	3.75 a	2.47 a
LSD (.05)	1.50	1.32	0.64
p > F	.77	.95	.50
Suppression × Row Interaction:			
p > F	.35	.68	.44
1 df Contrasts:		p> |t|	
Mono- vs Intercrop	.07	.005	.08
Un- vs Suppressed	.02	.04	.23
Mowed vs Rototill	.0006	.001	.16
Mow 2x vs Mow 5x	.05	.12	.17
Single vs Double Row	.89	.95	.89
Single + Double vs Triple	.49	.68	.44

[x] A minimum of 28 cm long and 6 cm wide.
[y] Mean separation by the LSD (.05).
[z] Probability of a greater ANOVA F-value.

free planting strips for corn, unsuppressed white clover reduced marketable corn yields in 1986 compared to clean cultivation, and mechanical suppression by mowing did not alleviate this interference (Table 1). Mowing 5 times during the season was only slightly more beneficial to corn yields than mowing twice, and neither mowing treatment markedly improved on the poor yields of corn obtained when clover was unsuppressed. Vrabel (1983) found that cutting white clover 3 times during the season resulted in sweet corn yields greater than with unsuppressed clover and similar to those with clean cultivation. Peters (1986) mowed clover 3 times during the season and obtained corn yields similar to those with atrazine-suppressed clover. The lesser effectiveness of mowing for suppressing clover in this study may have been due to the use of a rotary bagging mower which cut clover to a height of 15 cm and removed the clippings from the field. A hand-held string trimmer which cut the clover to a height of 2 to 4 cm was used in the earlier studies, and the clippings were not removed. While severe cutting may reduce the competitive ability of clover, moderate defoliation may actually increase its competitive advantage over an associated species (Donald, 1963; Harris, 1987). In addition, when clover residues and the N they contain are removed from the cropping system, competition for N between the crops may be intensified. Mowing generally suppresses white clover only briefly, as evidenced by the rapid recovery of N fixation from an abrupt decline following defoliation (Chu and Robertson, 1974) and by the vigor of regrowth in the field following mowing (Vrabel, 1983; Peters, 1986).

In contrast to mowing, partial rototilling of white clover 6 weeks after corn emergence in 1986 resulted in a marketable corn yield comparable to clean cultivation and greater than with unsuppressed clover (Table 1). Apparently, rototilling mitigated interference from clover during the year of establishment. In 1986, sweet corn yields with rototilled clover or clean cultivation were comparable to the average state yield of 7.95 mt ha^{-1} (NYS Dept. Ag. and Mkts., 1988).

Because partial rototilling showed promise as a means of suppressing clover in the 1986 trial, several rototilling dates were compared in the 1987 trial. When white clover was rototilled 2, 4, or 6 weeks after corn emergence, greater corn yields resulted than with clean cultivation or with unsuppressed clover (Table 2). Rototilling on 27 June resulted in the largest marketable yield of corn, almost 11 mt ha^{-1}, which fell by 19 percent and 30 percent when rototilling was delayed until 11 July and 24 July, respectively. Corn yields from the rototilling treatments compared favorably to the 1987 state average of 8.62 mt ha^{-1} (NYS Dept. Ag. and Mkts., 1988). Unlike in 1986 and in previous studies, unsuppressed clover did not reduce corn yields compared to clean cultivation. However, yield of clean cultivated corn was much lower in 1987 than in 1986, while corn grown with unsuppressed clover yielded similarly in both years. The poor corn yield with clean cultivation in 1987 was due in part to the greater incidence of corn smut in bare ground plots than in mixed culture (Table 2) and in part to the low rate of fertilizer N that was applied. Severe soil crusting was also evident in clean cultivated plots in 1987, and although stands were not affected, seedling vigor was. This condition appeared to be mitigated in mixed culture by the incorporation of clover residues during corn planting strip preparation, as were the N deficiency symptoms that were apparent in clean cultivated corn.

Corn N nutrition

Corn leaves were sampled throughout the experiments primarily to determine

Table 2. Sweet Corn Yields and Incidence of Corn Smut (*Ustilago mays*) in 1987

	Unhusked Ear Fresh Weight, mt ha^{-1}			
	Total	Marketable[x]	Cull	Primary Ears Infected with Smut (%)
Suppression Treatment:				
Clean Cultivated	3.62 c[y]	2.15 c	1.48 b	35.4 a
Rototilled 6-27	13.02 a	10.71 a	2.31 a	15.1 c
Rototilled 7-11	10.83 ab	8.63 ab	2.20 a	15.8 c
Rototilled 7-24	9.18 b	7.17 b	2.01 ab	24.3 b
No Suppression	5.96 c	3.95 c	2.01 ab	28.1 ab
LSD (.05)	2.35	2.20	0.66	9.6
p > F[z]	.0001	.0001	.13	.0002
Row Arrangement:				
Single	9.45 a	7.36 a	2.09 a	23.4 a
Double	8.92 ab	6.91 ab	2.01 a	23.3 a
Triple	7.19 b	5.29 b	1.90 a	26.1 a
LSD (.05)	1.82	1.70	.66	7.4
p > F	.04	.05	.74	.68
Suppression × Row Interaction:				
p > F	.08	.07	.03	.45
1 df Contrasts:	p> |t|			
Mono- vs Intercrop	.0001	.0001	.02	.0001
Un- vs Suppressed	.0001	.0001	.55	.005
Roto: 2 wk + 4 wk vs 6 wk	.01	.01	.40	.16
Roto: 2 wk vs 4 wk	.07	.06	.74	.04
Single vs Double Row	.55	.59	.75	.97
Single + Double vs Triple	.01	.02	.49	.41

[x] A minimum of 28 cm long and 6 cm wide.
[y] Mean separation by the LSD (.05).
[z] Probability of a greater ANOVA F-value.

the relative N status of the plants in different treatments, not to determine critical leaf concentrations to be used as diagnostic criteria. The experiments were conducted with sub-optimal rates of fertilizer N in order to avoid masking the effect of a suppressed clover mulch benefit to corn.

On 22 July 1986, immediately after rototilling the young but vigorous clover, the leaf N content of intercropped corn was lower than that of clean cultivated corn (Figure 2), and intercropped corn leaves appeared paler than those in monoculture. The recently established clover was likely competing for N with corn. Excavated clover roots indicated that it had not nodulated fully, and it is likely that a lot of the fertilizer N, plowed down 3 months earlier, had leached from the coarse soil during heavy rainfalls, including over 4 cm of rain on both 21 May and 1 June. However, 4 weeks after rototilling clover, about the time of silking, corn leaves appeared darker green and contained more total-N than leaves in other treatments, suggesting an N benefit to corn from rototilling the clover strips. About 22 kg N ha^{-1} in clover foliage was incorporated at the time of rototilling. Moreover, tillage *per se* may have influenced biotic processes and soil physical properties to indirectly improve the N nutrition of corn.

In 1987, 10 days after the first clover rototilling was imposed, there were no significant differences in corn leaf N content among treatments (Figure 3) owing to the recent application of fertilizer N in all plots, and all corn foliage appeared dark green. However, one month after the first rototilling, corn leaves in previously rototilled plots contained more total-N than corn leaves from any other treatment. Similarly, a month after the second rototilling treatment, corn leaf N concentration in this treatment was greater than in any other treatment except the earlier rototilling. By harvest, rototilling clover on any of the 3 dates had increased corn leaf N compared to no clover suppression or clean cultivation. The earlier the rototilling, the earlier in the season corn leaf N increased compared to clean cultivated corn. By the end of the season the leaves of clean cultivated corn not only contained less N than corn grown with rototilled clover but also appeared N deficient. Analysis of clover foliage indicated that, in 1987, 21 kg N ha^{-1} was incorporated during corn planting strip

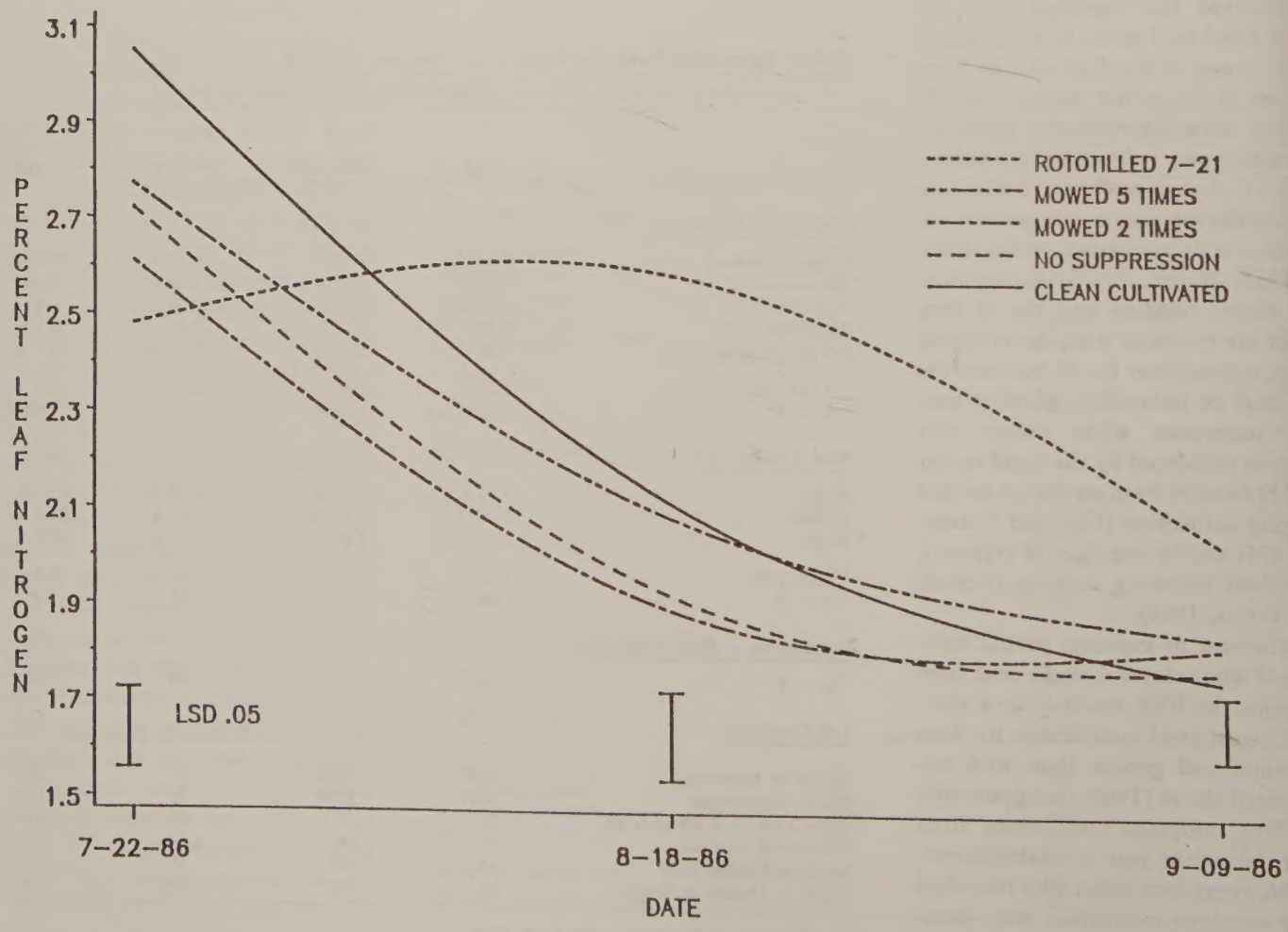

Figure 2. Sweet Corn Leaf Total-N Content in 1986.

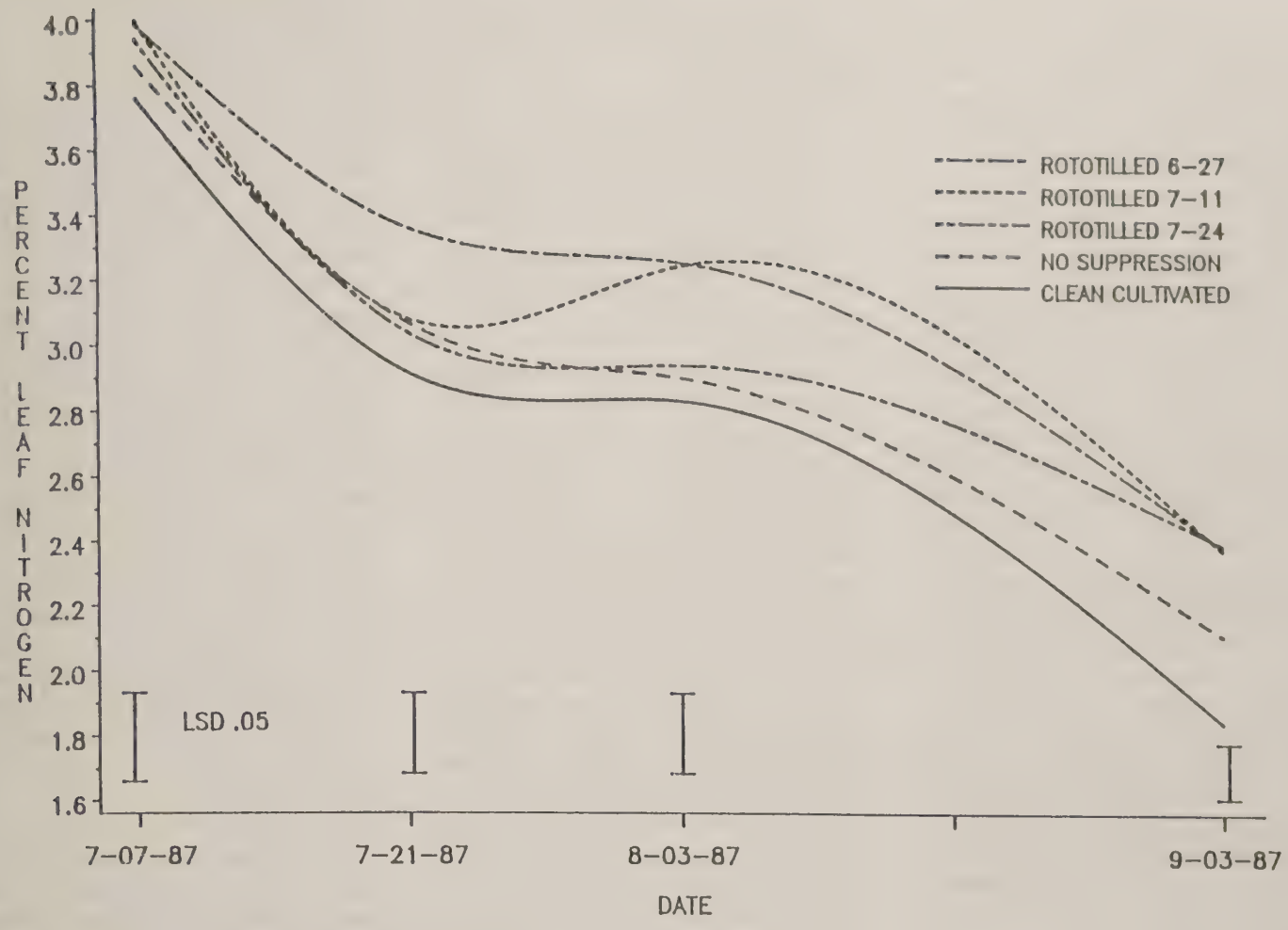

Figure 3. Sweet Corn Leaf Total-N Content in 1987.

preparation, and an additional 25 kg N ha^{-1} was turned under when clover was suppressed by rototilling.

Concentrations of total-N reported to be adequate in sweet corn ear leaves around the time of silking range from 2.6 percent to 3.5 percent, and 3.0 percent has been used as a critical concentration (Geraldson et al., 1973; Reuter and Robinson, 1986). Total-N concentrations found in corn ear leaves in 1986 ranged from 1.9 percent to 2.6 percent about the time of silking, suggesting N deficiency in most of the treatments. Leaf N concentrations at early silking in 1987 ranged from 2.8 percent to 3.3 percent, suggesting N sufficiency in the treatments with the higher leaf N levels.

Very low concentrations of NO_3-N were found in corn leaves during both growing seasons (data not shown), indicating that the N taken up by corn was rapidly assimilated. In 1986, corn leaf NO_3-N content did not differ among treatments on any of the sampling dates. At silking, uniformly low levels of leaf NO_3-N were detected, generally under 500 ppm, suggesting a deficiency of N in sweet corn (Lorenz and Maynard, 1980), as did leaf total-N levels. In 1987, intercropped corn contained higher levels of leaf NO_3-N than monoculture corn on all sampling dates except at harvest. Nevertheless, at early silking, despite total-N concentrations which were higher than in 1986, leaves still contained only about 500 ppm NO_3-N.

Although the present experiments were not designed to elucidate the mechanism for the improved N nutrition of the corn which was observed after clover suppression, several points bear mentioning. Part of the response is apparently due to the low level of N fertility under which the experiments were conducted. Although 91 kg N ha^{-1} was applied in 1986, much of it was probably leached from the coarse textured soil by the heavy rains preceeding corn planting, as previously described. In 1987, only 46 kg N ha^{-1} was applied as a topdress directly in the corn rows after planting. The reasoning above is consistent with the observations of Peters (1986) who obtained sweet corn yields with an atrazine-suppressed white clover mulch that were 153 percent, 121 percent, 119 percent, and 118 percent of clean cultivated corn yields when 0, 56, 112, and 168 kg of N were applied per hectare, respectively. Theoretical interpretations of intercrop design have also suggested that low rates of fertilizer N

favor a positive effect of intercropping with a legume, e.g., an augmentation of the N supply with biologically fixed N which could be negated if the system were saturated with N fertilizer (Vandermeer, 1984).

The loss of root and nodule tissue following stress could be a meaningful source of clover N for the associated corn. Fruiting, temperature, and soil moisture extremes (Wilson, 1931), shading (Butler et al., 1959), and defoliation (Wilson, 1942; Butler et al., 1959; Simpson, 1965; Chu and Robertson, 1974) have been reported to increase the loss of nodules from legume roots. Application of atrazine to the clover would seem analagous to this kind of stress. On the other hand, partial rototilling is a more intense form of suppression, as much of the foliage and roots are actually incorporated into the soil, as with green manuring. However, both methods of suppression could cause the release of N following the death of leguminous plant parts and thus limit competition for existing N. Moreover, rototilling might alter the amount of residual soil N mineralized and affect the physical properties of the soil in such a way as to enhance nutrient and water uptake and plant growth.

Row arrangement

Growing corn in multiple, narrowly spaced rows with wider mulch strips between grouped rows improves access to and facilitates mechanical suppression of the mulch crop compared to conventional single rows. In both years corn yields from single- and double-row arrangements did not differ significantly (Tables 1 and 2). Rutger and Crowder (1967) compared single-row corn spacings of 46 cm and 92 cm to double rows 15 cm apart on 92 cm centers at a population of 88,000 plants ha^{-1} in central New York and found no significant differences in dry matter or grain yield from the change in arrangement. In an Ohio study in which corn row spacings were compared in monoculture at a population of about 30,000 plants ha^{-1}, increasing row width from 76 cm to 203 cm by increments of about 25 cm caused only a slight decline in yield, which increased, as inherent soil fertility decreased (Stringfield and Thatcher, 1951).

In 1987, yields in triple-row arrangements were reduced as a result of lowered productivity of plants in the middle row of the 3 rows (Table 3). There was no interaction between row arrangement and clover suppression on marketable corn yield in 1986, but in 1987 there was a trend (significant at the 7 percent level of probability) whereby corn in triple rows was less affected by unsuppressed clover than corn in single rows (Tables 1 and 2). However, triple-row corn did not benefit as much as single-row corn from the early clover rototilling, suggesting that single-row arrangements encouraged more inter-specific interaction and possibly N transfer, while triple rows enhanced intra-specific competition among corn plants.

In 1987, no differences in corn leaf N concentration were observed among row arrangements. Similarly, in 1986, corn leaf N content did not differ significantly among row arrangements, except early in the season, when single-row corn had a slightly lower leaf N concentration than triple-row corn. There was no interaction between suppression treatment and row arrangement in their effect on leaf total-N or NO_3-N content in either year, except for total-N at harvest in 1987. In this case, only in the plots where clover was most recently rototilled did corn leaves from single rows tend to have higher leaf N concentrations than leaves from triple rows. Corn leaves from clean cultivated plots showed the opposite trend.

Incidence of corn smut

There was no appreciable loss of yiel due to corn smut (*Ustilago mays*) i 1986; but in 1987, losses to smut range from 15 percent to 35 percent of primar ears (Table 2). Suppressing clover b partial rototilling 2 or 4 weeks after cor emergence reduced losses from smut t about half that observed in the clea cultivation or unsuppressed clover plot Intercropping may have an effect on di ease levels by influencing spore dissem ination and modifying the plan environment (Sumner et al., 1981), bu little difference in the extent of smut wa observed between corn grown with un suppressed clover and that grown i monoculture. The incorporation of clo ver during rototilling more likely influ enced the subsequent development o smut. Teliospores may have been buried during rototilling and/or corn N stres and susceptibility to disease lessened b the addition of clover N to the soil.

Ground cover

The proportion of the soil surface no covered by clover, residues, or weed was estimated following each exper ment in the clover strips growing be tween triple corn rows. Three week after corn harvest in 1986, and in mid winter following the 1987 season, mor of the soil surface between groupings o corn rows was covered in living mulc plots than in clean cultivated plots (Ta ble 4). In 1986, mowed clover plots ha more ground cover than rototilled plots with no effect of mowing frequency

Table 3. Main Effect of Row Arrangement on Yield per Sweet Corn Plant in 1987

	Unhusked Ear Fresh Weight (kg plant^{-1})
Location:	
Single Row	.176 a[x]
Double Row	.176 a
Triple Row	.139 b
Location:	
Triple Arrangement: Outer Row	.161 a[x]
Triple Arrangement: Inner Row	.061 b

[x] Mean separation by the LSD (.05)

Table 4. Effect of White Clover Suppression on Subsequent Ground Cover

	% of Soil Surface Exposed[1]
30 September 1986	
Clean Cultivated	62.5 a[2]
Mowed 2 times	6.7 c
Mowed 5 times	10.4 c
Rototilled 7-21	19.6 b
Unsuppressed Clover	12.5 c
1 February 1988	
Clean Cultivated	72.1 a
Rototilled 6-27	12.5 b
Rototilled 7-11	20.8 b
Rototilled 7-24	15.8 b
Unsuppressed Clover	12.9 b

[1] mean of visual ratings from twelve 0.5 m^2 quadrats per treatment placed along mid-section of clover strips between triple rows of corn.
[2] mean separation by the protected LSD (.05) based on arcsin-transformed data.

However, the partial rototilling did not preclude substantial clover regrowth. In mid-winter following the 1987 season, clean cultivated plots again had more soil exposed than did living mulch plots.

Interpretive Summary

These trials were conducted to determine the feasibility of mechanically suppressing white clover living mulch grown with sweet corn. Mowing clover to a height comparable to that achieved with farm machinery did not sufficiently suppress clover. Partial rototilling of clover proved to be an effective means of non-lethal suppression, as indicated by corn yields and clover regrowth. As long as a strip of roots was allowed to pass intact between the central tiller tines, regrowth of the clover via stolons was extensive. Rototilling well-established clover 2 rather than 4 or 6 weeks after corn emergence was most efficacious. Under conditions of low N fertility, the N nutrition of corn appeared to be enhanced by intercropping with rototilled clover, as indicated by increases in leaf total-N levels within a month of rototilling. When the presence of corn smut was appreciable, corn grown with suppressed clover suffered less loss than clean cultivated corn.

The results indicate that there is promise for utilizing perennial, stoloniferous crops as living mulches when competitiveness is controlled by strip planting and partial rototilling. Such a system could protect the soil from erosion and structural deterioration, while utilizing N from a leguminous mulch crop. The extent to which an associated intercrop could utilize legume N likely depends upon cultural practices and edaphic and climatic conditions. The cropping system described here could be useful for vegetable production in the northeastern U.S., particularly where soil erosion and compaction are problematic. A living mulch system is risky without irrigation, but the same could be said about most vegetable production. Management of an intercrop system is more complex than with monoculture, and cultural practices such as weed control methods would have to be adapted to a mixed cropping system. This might involve more labor than required with monoculture. There is potential for improving this system, for example, by developing more strongly stoloniferous cultivars of white clover better suited to regrowth after partial rototilling and by developing corn cultivars better suited to intercropping.

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UPCOMING EVENTS

September 6-7. 1990 Field Days at Thompson Farm. For information contact the Rodale Institute, 222 Main Street, Emmaus, PA 18098; (215) 967-5171, ext. 1407.

September 10-16. Organically Grown Week, national celebration of organic farming and sustainable agriculture. The national committee has a guide and other materials to help individuals, organizations, and businesses participate. For information contact Organically Grown Week, P.O. Box 1300, Colfax, CA 95713.

September 23-27. The Australian Organic Agriculture Conference, a regional conference of the International Federation of Organic Agriculture Movements, in Adelaide, South Australia. Contact Elisabeth Eaton, Conference Secretariat, Festival City Conventions, P.O. Box 986, Norwood, SA 5067, Australia; (08) 269-4663.

September 26-29. International Symposium on Agroecology and Conservation Issues in Temperate and Tropical Regions, in Padova, Italy. The emphasis will be on the interrelation and transfer of research and application in sustainability and environmental problems between temperate and tropical areas of the world. For information contact M. G. Paoletti, Department of Biology, Padova University, via Trieste, 75, 35100-Padova, Italy.

October 10-14. BioCulture 90, a fair for organic farming, natural foods, and alternative energies, in Madrid, Spain. Contact BioCultura, Gran Via 618, 08007, Barcelona, Spain.

October 14-17. Role of Farmers in Farming Systems Research-Extension and Sustainable Agriculture, sponsored by the Association for Farming Systems Research-Extension, at Michigan State University, Lansing, Michigan. For information contact the 1990 AFSR-E Symposium Program Office, Institute of International Agriculture, 324 Agriculture Hall, Michigan State University, East Lansing, MI 48824.

October 22-25. Biodiversity and Landscapes, an international conference organized by the Center for BioDiversity Research and others at Pennsylvania State University. For information contact Dr. K. C. Kim, 117 Land and Water, Center for BioDiversity Research, Pennsylvania State University, University Park, PA 16802; (814) 863-0159.

October 22-26. International Symposium on Goat Production, in Tallahassee, Florida. Contact Claude McGowas, Room 202, Perry Paige Building, Florida A & M University, Tallahassee, FL 32307; (904) 599-3546.

November 8-9. Pesticides in the Next Decade: Third National Pesticide Research Conference, sponsored by Virginia Water Resources Research Center, in Richmond, Virginia. Topics include environmental degradation of pesticides, pesticide monitoring, risk assessment, alternatives, etc. Contact the Virginia Water Resources Research Center, Virginia Polytechnic Institute and State University, 617 North Main Street, Blacksburg, VA 24060-3397; (703) 231-5624.

November 14-16. New Ideas for Sustaining Farm Profits, sponsored by the Center for Holistic Resource Management, in North Platte, Nebraska. The Center is a nonprofit farmer, rancher, conservationist organization. Contact the Center at 800 Rio Grande Boulevard, NW, Suite 12, Albuquerque, NM 87104; (505) 242-9272.

November 19-22. Asian Farming Systems Research and Extension Symposium 1990, sponsored by the Asian Institute of Technology, in Bangkok, Thailand. The theme will be "sustainable farming systems in 21st century Asia." For more information contact Zenaida M. Bautista, Coordinator, 1990 Asian Farming Systems Research and Extension Symposium, FSRE Secretariat-B113 AIT Center, Asian Institute of Technology, GPO Box 2754, Bangkok 10501, Thailand.

December 2-5. Midwest Fish and Wildlife Conference, in Minneapolis, Minnesota. A day-long session will address "Changing Farm Practices: Sustainable Benefits for Fish and Wildlife?" Papers and poster sessions are invited. For information on the special session, contact Ann Robinson, Izaak Walton League, 801 Commerce Drive, Decorah, IA 52101; (319) 382-2947.

Insect pollinators and sustainable agriculture

Peter G. Kevan, E. Ann Clark, and Vernon G. Thomas

Abstract. *Underestimation of the pivotal role played by managed and native insect pollinators is a key constraint to the sustainability of contemporary agricultural practices. The economic value of such insects to pollination, seed set, and fruit formation greatly outweighs that suggested by more conventional indices, such as the value of honey and wax produced by honeybees. Although the European honeybee has been widely regarded as the single most important pollinating species, the increasing spread of trachael and Varroa mites and Africanized bees threatens the distribution and magnitude of traditional honeybeekeeping enterprises in North America. A number of other bee and insect pollinators, such as orchard bees, bumblebees, and squash bees, which are not affected by either the mites or the Africanized bees, are considered as likely candidates for management and use in commercial agriculture. An additional role can be played by native or wild pollinators, provided that attention is given to curtailing of population losses caused by both inadvertent insecticide poisoning and habitat destruction. To ensure a reliable source of pollinators, both managed and native, a more comprehensive strategy for management of crop pollination is needed. Elements of this strategy include an increased understanding of the biology and ecology of pollinating insects, as well as providing appropriate nesting habitat, and ensuring the availability of alternative sources of "forage" to sustain populations when the target crops are not in bloom. Examples are discussed to illustrate how private initiatives and changes to public policy can enhance pollinator habitat, and ultimately, agricultural productivity.*

Key words: orchard bees, bumblebees, squash bees, ecology, habitat conservation, private initiatives, public policy, alternative pollinators

Introduction

Agriculture that is sustainable explicitly recognizes its ecological foundations (Commoner, 1972; Altieri, 1987). Conversely, agricultural practices which fail to acknowledge and enhance flows of energy and material through natural processes, or worse, which eclipse and disrupt such processes, become increasingly dependent on exogenous subsidies of energy and material to sustain productivity (Clark and Christie, 1988). At present, design and management of sustainable agricultural systems are at risk because of ignorance of the contribution of managed and native insect pollinator species to the function of ecosystems and, specifically, to managed agroecosystems.

Principles of pollination

Pollination is the first step in the sexual reproduction of plants. It is the transfer of pollen from the male organs or anthers to the female receiving elements, the stigmata. As such, pollination is an essential prerequisite to seed and fruit development on most temperate and tropical crops. Furthermore, irrespective of whether or not the crop commodity is cereal, oilseed, vegetable, or forage, seed production for replanting most agricultural and horticultural crops also relies on pollination. Thus, it may truly be said that pollination is a pivotal, keystone process in both natural and managed ecosystems (Kevan and Baker, 1983, 1984).

Self-pollination and cross pollination (Figure 1) may be effected by gravity, wind, or animals (mostly insects). Some crops, such as varieties of soybean (*Glycine max* (Merrill) L.) and barley (*Hordeum vulgare* L.) are self-pollinating before the flowers open (cleistogamy). Others which are self-pollinating and entirely self-compatible are pollinated after the flowers open (chasmogamy), a common situation for crop plants and weeds. Nevertheless, even some self-pollinating crops produce better when outcrossing occurs, as has been found in canola (*Brassica napus* L.) (Kevan and Eisikowitch, 1990), and in self-compatible varieties of sunflower (*Helianthus annuus* L.) (Freund and Furgala, 1982) and soybean (Erickson et al., 1978). In self-incompatible plants, self-pollination will not effect fertilization, and outcrossing is required, as for many stone and pome fruits.

Floral morphology reflects the means of pollination. For example, wind is the primary agent of pollen transfer in forage grasses, which are equipped with large, feathery stigmata, prolific pollen production, and inconspicuous flowers. But for many species with colorful, scented, and conspicuous flowers, pollination is the outcome of the lengthy coevolution of plants and their pollinators (Crepet, 1983). The most abundant and diverse pollinators are insects, which may transfer pollen within or among flowers on the same plant, as in self-pollinating species, or between flowers on different plants, as is required by obligately cross-pollinated species.

Insect pollination in agriculture

The importance of insect pollination has been documented in treatises by Free (1970), McGregor (1976), and Pesson and Louveaux (1984). The economic value of insect pollination to all agricultural production in Canada and the

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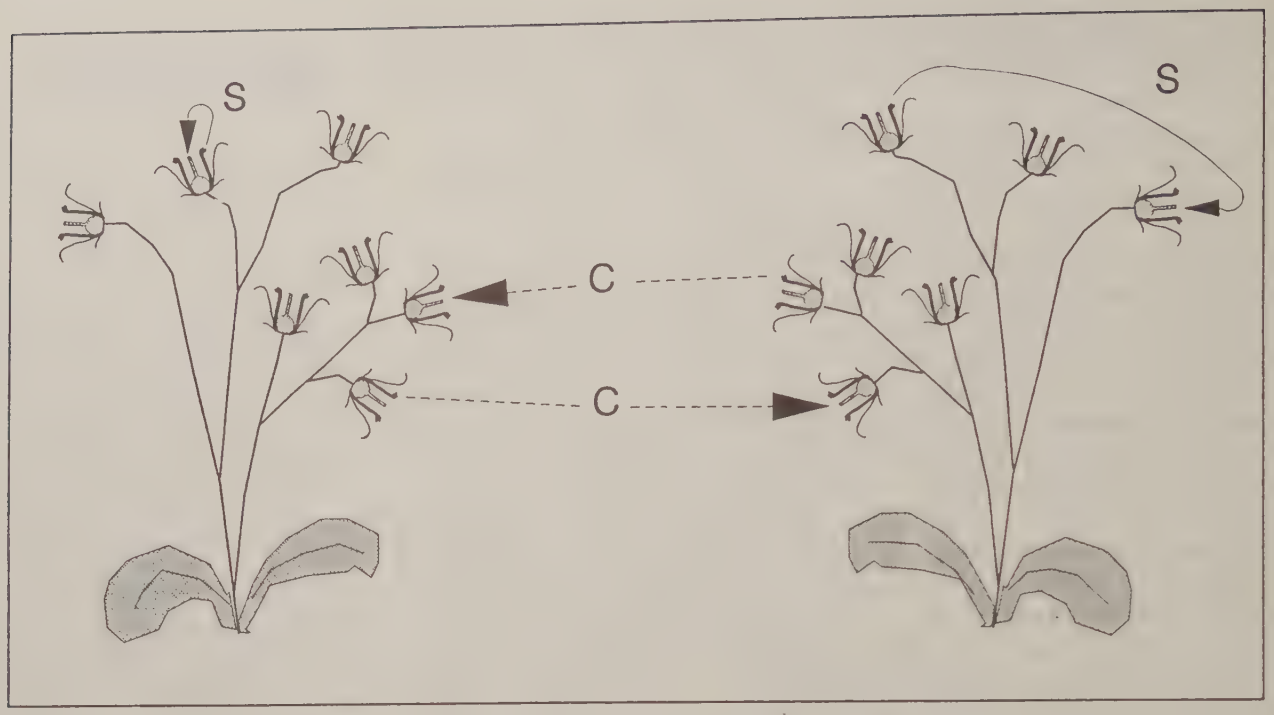

Figure 1. Cross and Self Pollination

U.S.A. has been estimated at $1.2 and $19 billion, respectively (Winston and Scott, 1984; Levin, 1983). In addition to the value of honey and wax produced by honeybees, these figures reflect the far greater contribution of insects to seed set and fruit formation in commercially grown crops. More recently, Robinson et al. (1989) have reviewed the contribution of honeybees alone to crop production and arrived at a figure of $9.3 billion annually in the U.S.A.

Because of its manageability and degree of domestication, the European honeybee, *Apis mellifera* L. has come to be regarded as the single, most important pollinating species (Free, 1970; McGregor, 1976; Jay, 1986). As large field monocropping and chemically intensive agriculture have become more prevalent, reliance on managed bees, especially honeybees, has grown. Moreover, removal of wild lands through agricultural expansion has disrupted the habitat of native pollinators. Insecticide application has killed them directly, and herbicide use has extirpated alternative pollen sources from their natural forage species (Kevan, 1975, 1986).

At present, impending risks associated with the overdependence of large-scale agriculture on honeybees for commercial scale crop pollination are becoming increasingly apparent (Robinson et al., 1989). One threat comes from parasitic trachael mites (*Acarapis woodi* Rennie) and varroa mites (*Varroa jacobsoni* Oudemans), which have severely afflicted the U.S. honeybee industry (Morse, 1988) and which will, in all likelihood, be prevalent in Canada within several years. Effective control of these exotic parasites, which affect only honeybees, is not simple, and practical control measures are still under development. Another threat is that of the Africanized (or "killer") honeybee, which is rapidly expanding its range in North America (Needham et al., 1987; Morrison, 1989). Little is known about the effects this aggressive and difficult to manage honeybee will have on crop pollination (Danka and Rinderer, 1986). In addition, honeybees do not pollinate all kinds of crops with equal efficiency, are not active under all climatic conditions, and may show species preferences (Kevan, 1987). Conversely, other species of bees may pollinate some crops at higher levels of efficiency, with lower population densities, and with greate independence of climatic condition (Boyle-Makowski, 1987; Torchio, 1987)

Accordingly, the position advocate in this paper is for recognition of th limitations of honeybees and for an ex panded role for native species in th commercial pollination of cultivate crops. We examine how natural polli nators, as a component of agroecosys tems, can be enhanced as a reliabl adjunct to honeybees. Finally, we inves tigate the conditions which must be sat isfied, including habitat, alternativ forage, reduction of chemical pollutants and shelter, for such native species t play a realized, economic role in modern agroecosystems.

Pollination and food production

Crops and their pollination

The central role of pollination in ag riculture is illustrated in Figure 2. Fa miliar foods which depend entirely o partially on insects for pollination in

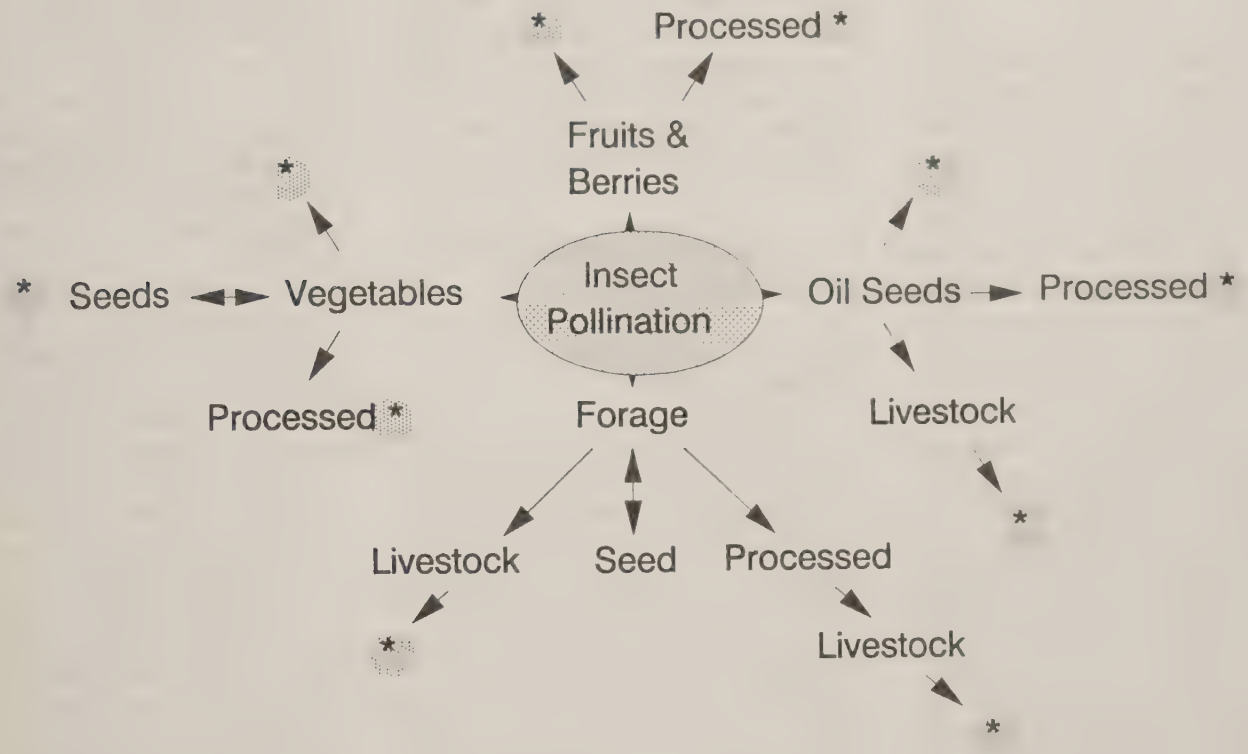

Figure 2. Insect Pollination and the Consumer

clude apples (*Pyrus malus* L.), pears (*P. communis* L.), blueberries (*Vaccinium* spp.), strawberries (*Fagaria* x *ananassa* Duchesne), raspberries (*Rubus* spp.), cherries (*P. avium* L.), pumpkins (*Cucurbita pepo* L.), squash (*C. maxima* Lam.), oranges (*Citrus sinensis* Osbeck), almonds (*P. amygdalus* Stokes), and a host of others in temperate and tropical parts of the world (Free, 1970; McGregor, 1976). Oilseed crops such as oil palm (*Elaeis guineensis* Jacq.) and some varieties of rapeseed (*Brassica* spp.) and sunflower (*Helianthus annuus*) are also dependent on insect pollination, as are forage legumes such as alfalfa (*Medicago sativa* L.) and the clovers (*Trifolium* spp.).

Some fruits (in the botanical sense) do not benefit from insect pollination. Wind pollination is well known in cereals and in walnuts (*Juglans* spp.), hazelnuts (*Coryllus* spp.), olives (*Olea europea* L.), dates (*Phoenix dactylifera* L.), pistachio (*Pistacia* spp.), grapes (*Vitis vinifera* L.) (Pesson and Louveaux, 1984), conifers, and many trees of the temperate zone. Others, such as tomatoes (*Lycopersicon esculentum* Mill), bell peppers (*Capsicum annuum* L.), eggplant (*Solanum melongena* L.), some beans (*Phaseolus vulgaris* L.), oilseed crops such as soybean and flax (*Linum usitatissimum* L.), are easily self-pollinated, either spontaneously or by some wind agitation. In addition, bananas (*Musa* sp.) and salad long cucumbers (*Cucumis sativa* L.) produce fruit without pollination.

Although much is known about crop pollination, areas of considerable ignorance remain. Much of the accepted knowledge on crop pollination is now out of date, some has little scientific basis, some is long-cited but unsubstantiated opinion, and some is simply wrong. There is no reliable compendium of information on pollination requirements of crops and pollinator management which can be applied to new crops, new varieties, new planting or cropping practices. Kevan (1989) has pointed out that clear questions remain about the pollination requirements of fully half of the 40 crop species grown in Canada. The situation is even more acute for Third World crop pollination (Kevan, 1984). Even for major plantation crops, an understanding of pollination has only recently developed. For example, coconut (*Cocos nucifera* L.) pollination may be by wind or insects or both (Pouvreau, 1984a), while oil palm has only recently been recognized as being dependent on insect pollination (Syed, 1979; Kevan et al., 1986).

Pollinators and their rewards

Coevolution has produced a mutualism between pollinators and flowering plants. Insect pollinators have greatly expanded opportunities for genetic re-

combination in plants, a process which is integrally related to angiosperm evolution, adaptation, and diversity. In return, pollinating insects obtain nutrient-rich nectar and pollen.

Nearly all pollinators take nectar from flowers, although not all flowers produce nectar. Nectar is a sugary liquid with numerous minor components (Baker and Baker, 1983) and serves mostly as carbohydrate fuel for flight in pollinators. Not all floral nectars are equally useful to pollinators, and many special relationships are known in nature (Baker and Baker, 1983). Some pollinators, notably honeybees, bumblebees, and some other tropical bees, gather nectar and return with it to their nests (hives), where it is cured, made into honey, and stored. Thus, honeybees can be thought of as sophisticated biomechanical micromanipulators which gather and exploit a resource--nectar--which would otherwise be unharvestable and convert it into human-usable products. By channeling and encouraging their foraging and colonizing behavior, bees have been made to serve agriculture both directly, in the production of honey, and indirectly, via pollination of dependent crops.

From the perspective of honeybees, bumblebees, and a few other bees, honey represents the energy store for lasting out the winter or for shorter periods of bad weather or floral dearth. Towards their own sustenance and that of their brood, bees also gather pollen, a highly nutritious substance which is rich in proteins, carbohydrates, lipids, vitamins, and minerals (Stanley and Linskens, 1974). Pollen, together with nectar and nutritive glandular secretions from the bees, is fed to larval bees and provides their entire nutritional requirements until they metamorphose to become adults. As with nectar, not all pollen is equally valuable to bees. Conifer pollen, for example, has little nutritive value and is not usually taken by bees.

Solitary (not colony building) bees build their own nests which are comprised of cells provisioned with a loaf of pollen and nectar upon which they lay an egg. The bees seal up the individual cells, the egg hatches, and the larva develops while feeding on the loaf and eventually metamorphoses to become an adult. Other pollinators, such as flies (Diptera), moths and butterflies (Lepidoptera), and beetles (Coleoptera), ingest nectar, pollen, or both for their own nutrition and for the maturation of their gonads. The females do not contribute provisions other than what they have placed in the yolk of the egg.

The diversity and value of pollinators

Bees

A huge proportion of the world's insect fauna visits flowers for sustenance, but not all are efficient pollinators. Although bees are recognized as being among the most important pollinators in almost all ecosystems where flowers occur (excluding, for example, marine sea grasses), their precise roles in pollination are not well documented. Some 30,000 species of bees are known to science, ranging in size from tropical giants of nearly 8 cm long to minute sweat bees of about 2 mm in length. About 190 species of bees have been associated with pollination of lowbush blueberry in northeastern North America alone (Finnamore and Neary, 1978).

Honeybees

Despite the array of bees potentially available, only a few species, including honeybees, have been placed under some form of management. The presence of a viable honeybee industry in North America attests to the adaptation of this eusocial species to modern agriculture. In Europe and North America, the European honeybee (*Apis mellifera* ssp.) dominates, while in South and Central America, the Africanized honeybee (*Apis mellifera* x *scutellata*) or so-called "killer bee," has displaced the European bee in its inexorable spread (Needham et al., 1987; Morrison, 1989). In Africa, various native races of *A. mellifera* are pollinators, although there is little management of these honeybees for that purpose. In Asia, the Asiatic hive bee, *A. cerana* Fabr., occurs in the wild and is used for beekeeping and pollinatio Other wild honeybees, the giant or roc honeybee, *A. dorsata* Fabr., and the litt honeybee, *A. florea* Fabr., are importa in tropical and subtropical Asia. Eur pean bees have been introduced in Asia with some success (FAO, 1984 especially in temperate areas. In Au tralia and New Zealand, European h neybees were introduced in the earl 1800's for honey production and poll nation. Honeybees are used primarily f honey production, although in place such as Africa and South America, wa production is also of great importanc (Free, 1982). In only a few special place such as the Okanagan Valley of Britis Columbia and in parts of California, i pollination the main motivation f keeping honeybees. Thus, most hone bees act as pollinators as a side benef to their honey production.

Economic analyses of the value of in sect pollination to agriculture ha stressed the importance of honeybee (Eckert and Shaw, 1960; Levin, 198 1986; O'Grady, 1987; Robinson et al 1989; Winston and Scott, 1984), even i the context of wildlife habitat (Barcla and Moffett, 1984). Although som studies (especially O'Grady, 1987; Rob inson et al., 1989) attempt to ascribe percentage of crop production to the po linating activity of honeybees, the pro portions used are based on opinions o estimates by apiculturalists rather tha on rigorously gathered data. The "mos accepted estimates indicate that hone bees account for at least 80 percent o all insect pollination" (Robinson et al 1989). Another recent analysis (agai based on estimates) suggests that th value of honeybees is much lower tha that suggested above (E. E. Southwick 1989, personal communication).

The Province of Ontario serves as good example of how pollination take place in most agricultural settings. I 1988, there were 5,400 beekeepers an 115,000 colonies registered in Ontario Of these, only 280 beekeepers had mor than 100 colonies and could be catego rized as commercial beekeepers. O those, only 20 managed their bees fo pollination and provided a commercia service to crop growers (McRory, per sonal communication).

Thus, it can be appreciated that most crop pollination by honeybees is a free service done by a widely scattered population of honeybees in hives managed by hobbyists and by commercial honey producers.

Beekeeping in Ontario, in Canada, and in North America generally is in serious financial trouble. Commercial beekeepers are finding it increasingly difficult to make a profit because of the very low price of honey on domestic and world markets (ca US$0.80/kg in 1988) vs. the estimated cost of production at ca US$1.20/kg in Ontario (D. McRory, personal communication). The value of other hive products and pollination is very small. Mechanization in beekeeping has helped increase efficiency over the years (Free, 1982); but beekeeping is a labour-intensive operation, and the task of attending hives is not amenable to machine operation. Consequently, the number of commercial beekeepers and hives in Canada has declined over the last two decades.

Beekeeping in Canada is now threatened by two extremely serious diseases of honeybees which are prevalent in the U.S.A. (Needham et al., 1987; Morrison, 1989). These diseases, which are caused by the trachael mite, *Acarapis woodi,* and by the ectoparasitic mite of bee brood and adults, *Varroa jacobsoni,* afflict only honeybees. Both parasitic mites debilitate the honeybees they infect so that hives dwindle in strength and die out. Although control measures for these diseases are being developed and are available in other countries, they add to the complexity and cost of beekeeping. The mite diseases will enter Canada because of the natural movement of infected bees crossing the Canada/U.S. border and by the actions of irresponsible beekeepers importing bees from abroad. Once that happens, beekeeping will necessarily become a more sophisticated operation than it has been in the past. The running of efficient commercial operations will cost yet more, up to US$7.00/hive per year in supplies alone (D. McRory, personal communication). The cost of pollinator services, as they become scarcer and more needed, will rise.

Compounding this set of problems will be the likely decline in the number of hobby beekeepers, who will abandon or reduce their activity because of the additional labor and chemical inputs needed to control the parasitic mites. Thus, because of both higher costs and lesser numbers of operators, the free pollination service now provided by honeybees will likely be severely reduced.

Other bees

Although honeybees are recognized as the most valuable pollinators in agriculture worldwide, there are other noteworthy contributors. For example, the alkali bee, *Nomia melanderi* Cockerell, was among the first of the solitary bees to be used for pollination of alfalfa in the western U.S.A. Alkali bees burrow into the soil and make subterranean cells which are provisioned with pollen and nectar. Artificial bee beds are used to maintain these bees.

The alfalfa leafcutting bee, *Megachile rotundata* Fabr., is now widely used for alfalfa pollination. It naturally nests in tunnels previously made by woodboring insects in fence posts and trees. Its cells are made of pieces of leaf moulded into a minute thimble (ca. 1 cm long). Leafcutting bees are easy to manage and set out for alfalfa pollination (Richards, 1984), requiring less attention than do honeybees, but tend to prefer warm, sunny weather. Alkali bees require even less management, merely the establishment and protection of a special bed of soil in which they can nest (Stephen, 1960). Both the alfalfa leafcutting bee and the alkali bee are better than honeybees at "tripping" the complex floral mechanism which effects pollination. Honeybees tend to remove nectar without tripping and, hence, without pollinating, the flowers. Progress is being made in selecting alfalfa leafcutting bees which will work under the cooler, windier, and cloudier weather which typifies northern areas of alfalfa production in Canada (Pankiw, 1987).

The orchard bees, *Osmia* spp., also nest in tunnels in wood but make their cells with mud. For both *Megachile* and *Osmia,* artificial nesting tunnels can be manipulated, moved, and stored (Torchio, 1987). Orchard bees have been used for commercial pollination in various parts of the world, most particularly in Japan, where orchard bee culture is well developed. By comparison with honeybees, orchard bees are far superior for apple pollination. It has been estimated that 356 female bees are enough to pollinate an acre of an apple orchard, while several hives, each containing tens of thousands of honeybees, would be needed to achieve the same result (Torchio, 1987). Furthermore, orchard bees will forage during the orchard tree bloom, when the weather is cool, windy, cloudy, and damp, conditions which honeybees eschew. Orchard bees also forage widely throughout the orchard, rather than at a single tree or group of trees, as do honeybees. The use of orchard bees in pollination will probably increase as their value is recognized and as the cost of honeybees keeps rising.

Bumblebees, *Bombus* spp., have also been used for crop pollination but are expensive to manage and pose problems in rearing. These factors restrict their use to very high value crops (Plowright and Laverty, 1987). Bumblebees are mostly found in temperate climates. They are eusocial, like honeybees, but with smaller rather less structured nests, mostly underground in abandoned mammal burrows. The nests last but one year for most species. Inseminated queens are the final survivors which overwinter for the next year's generation. Bumblebees are the pollinators of choice for red clover (*Trifolium pratense* L.) and cranberries (*Vaccinium macrocarpon* Ait.). They have been introduced into New Zealand (Dunning, 1886) and Chile (Arretz and Macfarlene, 1986) for red clover pollination. In New Zealand, they are also being used to pollinate kiwifruit (*Actinidia chinensis* Planch) (Pomeroy, 1988). Bumblebees are probably very important pollinators of many crops, including alfalfa, fruit trees, and small berries, but they have not been sufficiently recognized as such. Pouvreau (1984b) provides an excellent review of the potential for bumblebees as pollinators. Recent developments in Holland indicate an important role for these bees in greenhouse pollination, especially of tomatoes (van Heemert, personal communication).

Carpenter bees (*Xylocopa* spp.) are

mostly tropical and subtropical. They may be excellent pollinators of vine crops, especially of passion fruit (*Passiflora edulis* Sims) (Bohart, 1962), giant granadilla (*P. quadrangularis* L.), kiwifruit, various gourds, and winged beans (*Psophocarpus tetragonolobus* (L.) DC.), but have not been the subject of much research. They bore into wood or rest in hollow stems, both of which can be easily provided in the settings where such crops are grown.

Squash bees, *Peponapis* spp. and *Xenoglossa* spp., which are related to carpenter bees, are more specialized but perhaps more manageable. Squash bees are specific to squashes, pumpkins, and gourds. One species of squash bee, *Peponapis pruinosa* (Say) has followed cultivation of *Cucurbita pepo* from the southwestern U.S. to southern Canada (Kevan et al., 1988). The bees nest in underground burrows. They become active at dawn, visiting cucurbit flowers until about midday when the unisexual flowers close. As a result, they typically start to pollinate the crop before honeybees are abroad and have finished by the time honeybees are at their most active, from midmorning on (Kevan et al., 1988). Squash bees could be kept in bee beds near farms specializing in these crops, as is currently under test on a vegetable farm in Ancaster, Ontario (Kevan and Willis, unpublished).

Other candidate pollinators among the native bees would include sunflower bees (*Eumegachile pugnata* (Say)) (Parker and Frohlich, 1985), blueberry bees (*Habropoda laboriosa* (Fabr.)) (Sanchez, 1989), and *Osmia ribifloris* Michener (Torchio, 1990a,b).

Other insect pollinators

Perhaps the most valuable specialty pollinator, in terms of world trade, has been the oil palm weevil, *Elaeidobius kamerunicus* (Syed, 1979; PORIM, 1985; Kevan et al., 1986). Until recently, it had been assumed, mistakenly as it turned out, that oil palm was pollinated by the wind. Thus, in southeast Asia, oil palms were either artificially pollinated or pollination was left to the vagaries of the wind or other insects. The careful introduction of the oil palm weevil from its native West Africa into Malaysia in 1981 has saved millions of dollars in labor, as well as improving crop performance (PORIM, 1985; Kevan et al., 1986).

Cocoa (*Theobroma cacao* L.) has specialty pollinators as well, but these are widespread non-biting midges, *Forcipomyia* spp., which breed in rotting vegetation (Pouvreau, 1984a). Thus, in most places, there is a resident population of midges for pollination. However, overcleanliness in cocoa plantations can result in crop failures (Winder, 1977). Efforts are now made to encourage midge populations by providing sections of rotting palm trunks, in which they can breed (Ismail and Ibrahim, 1986).

Losses of managed and wild pollinators

The likelihood of diminished populations of honeybees to pollinate commercial crops has focused attention on alternative pollinators, both managed and wild. The lack of adequate numbers of wild bees for crop pollination can be attributed to two interrelated processes: (1) direct poisoning by insecticides and (2) destruction of habitat for pollinators.

Insecticide-based losses

The devastating effects of insecticides on honeybees are well known (Johansen, 1977; NRCC, 1981), but the costs of these effects have not been well documented. The economic implications of the loss of pollinators to agriculture and to natural ecosystems may be envisioned from several case studies involving insecticides. In New Brunswick, the insecticide used to control a forest pest, the spruce budworm (*Choristoneura fumiferana* Clem.) was changed from DDT (dichlorodiphenyltrichloroethane) to the organophosphorus compound, fenitrothion (0,0-dimethyl 0-4-nitro-m-tolyl phosphorothioate), which is highly toxic to bees, in 1970. In blueberry fields near tracts of treated forest, the resulting demise of blueberry pollinators has been well documented (Kevan and LaBerge, 1979) and was cause for alarm because of the dependence of fruitset in lowbush blueberry on insect pollinators. A d cline of 665 tonnes/year in blueber production in New Brunswick coincide with the period during which fenitr thion was used and when its aftereffec could be assumed to be operatin (Kevan and Plowright, 1989), despite e forts of blueberry growers to circumver the loss of native bees by importing h neybees for pollination. The demise natural pollinators in the forests of Ne Brunswick, Quebec, and Ontario h also been documented to be associate with fenitrothion and other insecticid applications (Kevan and Plowrigh 1989).

Another example is for alkali bee where inadvertent pesticide poisoning i Washington was estimated to have co $287,000 in lost alfalfa seed productio in 1973 (Johansen, 1977). More recently the loss of honeybees caused by infectio by *Varroa* mites in Israel is thought t have resulted in losses of the cantaloup crop (*Cucumis melo* L.) (D. Eisikowitch personal communication).

Habitat-based losses

The consequences of habitat disrup tion on populations of pollinators woul warrant a greater research emphasis For example, the trend in agriculture t large-field monoculture has eliminate large areas of wildlife habitat and sorel affected pollinator populations. In Brit ain, for example, a reduction in the pop ulation of bumblebees has bee attributed to changes in land use. Wil liams (1986) attributes declines in th abundance and diversity of British bum blebees to increased amounts of culti vation, alteration of drainage and it consequent effect on the flora of bum blebee forage, removal of rough land an hedges at field margins, and uniformit of crop plants and, perhaps, climati change. Peters (1972) also considere some of these effects as causing decline in populations of bumblebees in Ger many.

In Canada, the centermost plants i large-scale alfalfa fields have been re ported to be poorly pollinated, with pro duction dropping from 1000 kg/ha t 150 kg/ha in 4 to 10 years of extensiv

land clearing. The elimination of land for nesting sites of native pollinators has been cited as the cause (Stephen, 1955). Benedek (1972) discusses the negative impact of weed control on populations of wild pollinators of alfalfa and of other flower visiting insects in Hungary.

Other crops which may suffer because of large-tract monoculture are cranberries (Kevan et al., 1983) and various fruit and nut crops, such as cocoa, cashews (*Anacardium occidentale* L.), North American paw paw (*Asimina triloba* (L.) Dunal) (Kevan, unpublished). Weed control on blueberry lands in Maine is now being considered as a main cause for the paucity of native bee pollinators (E. Osgoode, personal communication).

Meeting the needs of crop pollination in the future

Agriculture requires a secure source of reliable pollinators. As we have noted, the principles of honeybee use and management are well known; and honeybees are valued for their honey, wax, and other hive products. However, we have also argued that honeybees do not suffice for all crops or under all environmental conditions and that a variety of factors are pending which may unsettle and modify the status quo. From this analysis, it is concluded that a more comprehensive strategy for management of crop pollination will be needed in the future.

A variety of pollinators, ranging from highly managed to wild, will provide latitude and security in crop pollination. Beekeeping with honeybees must be encouraged, starting with a recognition of the problems and values of beekeeping. To ensure reliable pollination, growers will have to be more willing to pay for pollination services because the price of honey is set by market forces beyond national borders. However, honeybees should not be perceived as the ultimate and only pollinator for agriculture.

Examples of reliable alternative pollinators for specific crops are known for alfalfa, oil palm, and cocoa, as discussed above. Promising alternative pollinators for other crops include orchard bees, sunflower bees, blueberry bees, squash bees, and bumblebees (Torchio, 1987; Kevan et al., 1988). The huge diversity of wild pollinators indicates that the above examples are only the very tip of a highly valuable, if unrecognized, mother lode.

To manage, encourage, or conserve alternative pollinators requires a basic understanding of their biology and ecology. Nesting habitat must be provided, whether as a soil bed of a more or less special nature, or as stumps of trees and logs, or as rodent burrows for bumblebees. At present, too little is known to define and recommend the specific habitat requirements of most bees. However, providing relatively undisturbed field edges, hedgerows, fencelines, windbreaks, woodlots, ponds, streams, and stone piles would be expected to assist pollinators (Stephen, 1955; Williams, 1986). Provision of artificial nesting sites, such as wooden blocks or log ends with holes bored into them, cavities for bumblebees, and protected or managed beds of soil, would facilitate pollinator management.

The pollinators which are enticed to occupy habitats need alternate sources of forage when crops are not in bloom. For example, the annual cycle of a bumblebee colony involves overwintering by the queen, who establishes and rears the first cohort of worker bumblebees by herself in the spring. Eggs are then laid in the summer, after which the colony declines and all but the queens perish. Clearly, a persistent bumblebee colony requires sustenance throughout spring, summer, and fall.

Many solitary bees have relatively short lifespans which may not coincide exactly with the timing of a specific crop bloom. Thus, if a pollinator emerges as an adult slightly before a crop is in flower, or if the blooming period of the crop is shorter than the bee lifespan, additional floral resources are needed to support the bees. Other pollinators may have two or more generations per year. Thus, they may be pollinators at one time and forage on crops, but at other times, the generation of pollinators requires other sources of pollen and/or nectar.

To accommodate the various needs of bee populations, forage in the form of flowering "weeds," wild herbaceous plants, shrubs, vines, and trees must be available. Such plants can be allowed to thrive with little or no management or may be specially encouraged or sown. A number of examples serve to illustrate the principle, although individual sites and habitats will have different requirements. Willow (*Salix* spp.), for example, is an excellent source of nectar and pollen in early spring for a wide variety of pollinating insects. Marjoram (*Origanum* spp.) and clovers have long blooming periods and are a good source of nectar during the summer, as well as providing ground cover. Sweetclover (*Melilotus* spp.) is a valued bee crop in summer, and fall asters (*Aster* spp.) are productive pollinator forage late in the summer. In addition, a variety of other shrubs and trees may be used as windbreaks and as pollinator forage, including *Caragana* spp., *Prunus* spp., *Rosa* spp., and *Viburnum* spp.. For detailed documentation of plants which are good sources of nectar and pollen in Canada and the U.S.A., see Ramsay (1987) and Pellett (1976).

Land use changes and pollinator management

Native pollinator habitat can be enhanced by local initiatives on private lands, including thoughtful management of non-cultivated patches of ground, as noted above. Public policy can also assist through the setting aside of municipal and regional parks or protected areas for wildlife, flora, and fauna. For example, in the USSR, a park has been set aside for bumblebees, reflecting a degree of dedication that would be useful in areas particularly unique for or especially favorable to bumblebees, other bees, or for other rare or special plants and pollinators.

Along the edges of arable land, conservation authorities could facilitate planting of hedges and fence rows to species (see above) which would encourage pollinator populations. The extensive use of conifers on managed conservation areas should be discouraged in favor of a strategically selected mixture of species. For land rehabilita-

tion, along eroded streambanks, lakeshores, landfills, and other disturbed sites, a variety of herbaceous as well as shrubby and woody species would be preferable to the current practice of mostly hybrid poplars, maples, and conifers. Greater diversity would also provide more suitable habitat for small birds and mammals, as well as crop pollinators.

As already demonstrated in Ontario, birdsfoot trefoil (*Lotus corniculatus* L.) and crownvetch (*Coronilla varia* L.) are representative of good cover and bee forage crops for roadside and slope stabilization. In about 1974, a stretch of roadside in Ontario was planted to honeybee forage (G. F. Townsend, personal communication), but the present status of this area is unknown. R. Shuel (personal communication) suggests that about 40 kg of honey could be harvested from 1.6 km of florally rich country roadside in Ontario. Thus, areas such as roadsides, which are now managed to limit or inhibit vegetation, could be managed to enhance selected vegetation types with direct as well as indirect economic benefits.

Where possible, roadsides and highway verges should be mowed rather than chemically treated to keep vegetation low enough to ensure visibility for motorists (e.g., in Garafraxa Township, Ontario). Noxious weeds in Ontario are designated by the Ontario Weed Control Act (1974), which states that "Every person in possession of land shall destroy all noxious weeds thereon." Some "noxious" weeds are excellent nectar and pollen plants, including thistles (*Cirsium* spp.), milkweed (*Asclepias syriaca* L.), chicory (*Cichorium intybus* L.), and rocket (*Barbarea* spp.). The practicality of the Act notwithstanding, these weeds have considerable value in supporting the lives of flower visiting insects, especially pollinators (Benedek, 1972). Weed control has been cause for beekeepers' concerns about reduced forage for bees in various parts of the world (Crane, 1981; Crane and Walker, 1983).

Recent reviews (Altieri and Whitcomb, 1979; Altieri and Letourneau, 1982; Altieri and Schmidt, 1985, 1986; Andow, 1988) document that the incidence of pest insects is sometimes lower, and of predators and parasitoids can be higher, on crop plants close to weeds or uncultivated areas. These studies mention specifically the importance of nectar and pollen sources for beneficial biocontrol insects but do not consider the central process of pollination for crop production. Batra (1982) briefly notes the benefits of polyculture and weeds to pollinators and other beneficial insects but indicates that these benefits may be offset by the provision of alternative hosts and hibernaculae for pests. However, Van Emden and Williams (1974) indicated that insect pest movement into crops often can be attributed to the absence, rather than to the presence, of other plants near the crops. Clearly, there is need for recognition of both pollinators and other beneficial insects in assessing the costs and benefits of weeds and uncultivated land in cropping systems (Kevan, 1986).

A policy of providing and managing diverse pollinator habitats will aid in agricultural productivity, as well as enhancing the beauty of the rural landscape with colorful flowering species. Management of these habitats, including roadsides, rights of way for powerlines and railways, fencelines, hedgerows, woodlots, and streambanks with minimal use of chemicals will help restore some ecological diversity to potentially monotonous and visually sterile agricultural landscapes.

Conclusions

Rather than being an enemy to be overcome and conquered, nature can be an active and beneficial contributor to the practice of agriculture. Pollinators are a pivotal link in the natural economy of the earth, including agriculture and other human activities. Yet, the direct economic importance of insect mediated crop pollination and of the incalculable value of pollination in natural systems, by honeybees and, more critically, by native pollinators, has been overlooked and undervalued. At present, unfavorable economics, parasitic mites, and African bees threaten the extent and distribution of the honeybee industry in North America. These impending dangers expose the critical vulnerability of pollination-dependent crops in the absence of reliable populations of alternative pollinators, which have themselves been reduced by agricultural practices. A wide array of insects, some of which have been employed as specialty pollinators, is available to augment and reinforce the honeybee industry in commercial-scale crop pollination. However, only a handful have been investigated and fewer than 10 have been studied thoroughly enough to be in use for commercial crops. The lack of information on other candidate species stems more from overdependence on honeybees rather than on intrinsically insurmountable difficulties in the management of other pollinators. Studies on alternative pollinators are urgently needed.

The explicit encouragement of managed and native pollinators, by limited and strategic use of biocides, by planned habitat development and maintenance, and by field dimensions consistent with pollinator flight ranges, must be an integral part of newer approaches to food production through sustainable agriculture. Enlightened habitat management, whether through personal initiatives on privately owned land, or by development of ecologically responsive policies on public lands, will enhance populations of biocontrol agents and native pollinators to the benefit of agriculture as a whole.

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RESOURCES

Alternatives in Pest Management, from the University of Illinois Cooperative Extension Service, now includes four publications: *Microbial Insecticides* (C-1295, $1); *Botanical Insecticides and Insecticidal Soaps* (C-1296, $2); *Insect Attractants and Traps* (C-1297, $2); and *Beneficial Insects and Mites* (C-1298, $2). Request by title and number from the University of Illinois, Office of Agricultural Communications and Education, 69-02 Mumford Hall, 1301 West Gregory Drive, Urbana, IL 61801.

The Cost and Return Estimator, a computer program from the U.S. Soil Conservation Service, helps land users compare their current methods with more sustainable farming systems. Contact county SCS offices for more information.

GreenPrints, a literary gardening newsletter, focuses on inspirational writing for small growers; $10 for four quarterly issues. Contact GreenPrints, P.O. Box 1355, Fairview, NC 28730.

Agriculture Diversification Series, 14 publications from Iowa State University Extension, includes: "Rabbits," "Beekeeping," "Raspberries," "Strawberries," "Broccoli and Cauliflower," "Sod Production," "Fuelwood," "Sweet Corn," "Snap Beans," "Maple Syrup," "Christmas Trees," "Angora Goats," "Muskmelon," and "Perennials." Copies are free from Publications Distribution, Printing and Publications, Iowa State University, Ames, IA 50011, or Iowa county extension offices.

Synergy, a magazine from Saskatchewan, Canada, carries news, articles, and some research related to organic farming in Canada. The Spring 1990 issue (Vol. 2, No. 2) has an article by Stewart Brandt, of Agriculture Canada Experimental Farm, on Indian head lentil as a green manure substitute for summer fallow. Subscriptions are $12/year (Canadian) from Synergy, Box 9859, Saskatoon, Sask. S7K 7Z2, Canada.

Farming With Fewer Chemicals: A Farmer-to-Farmer Directory describes the operations of 39 no- or low-chemical Iowa farmers. It is $2 for farmers, $7 for non-farmers, from the Iowa Citizens for Community Improvement, 1607 East Grand Avenue, Des Moines, IA 50316.

Farmer Participation in Research for Sustainable Agriculture is a 102-page report from the 1989 conference of that title. Copies are $5.75 from Conference Report, ATTRA, P.O. Box 3657, Fayetteville, AR 72702.

1990 Organic Wholesalers Directory and Yearbook lists over 400 grower-wholesalers, distributors, and farm suppliers in North America and provides a guide to certification and support groups. Copies are $28 postpaid (California residents add $1.56 tax) from the California Action Network, P.O. Box 464, Davis, CA 95617.

1990 Organic Certification Handbook from the California Certified Organic Farmers (CCOF) is a newly revised, 42-page document that includes lists of acceptable materials. Copies are $10 from CCOF, P.O. Box 8136, Santa Cruz, CA 95061-8136.

Organic Certification (SRB-90-04) is a USDA bibliography on the topic dated January 1990. Single copies are free with a self-addressed label sent to the Reference Branch, Room 111, National Agricultural Library, Beltsville, MD 20705.

Environmentally Sound Small Scale Agricultural Projects, a revised edition prepared by Miguel Altieri, covers the planning process for a more sustainable small-scale agriculture, with a Third World perspective. The manual includes ecological concepts and other factors related to designing environmentally sound projects in the areas of water supply and management, nutrient management, soil conservation, pest management, and agroforestry systems. For information, contact VITA Publication Services, P.O. Box 12028, Arlington, VA 22209.

Sustainable Agricultural Systems, a book of papers from the 1988 international conference on sustainable agriculture held in Columbus, Ohio, is now available from the Soil and Water Conservation Society. Sections of the 40-chapter book include an overview of sustainable agriculture, components of sustainable agriculture systems, policy issues, and ecological impacts. The cost is $40 postpaid ($36 for SWCS members) from the SWCS, 7515 Northeast Ankeny Road, Ankeny, IA 50021.

Alternative Agriculture: Federal Incentives and Farmers' Opinions (GAO/PEMD 90-12) is a February 1990 report to Congress from the General Accounting Office. Federal farm programs reward farmers for specializing in program crops year after year, "resulting in further soil depletion and pest problems, which in turn lead to a greater need for agrichemical inputs," the GAO said. Farmers interviewed by the GAO listed obstacles to adopting alternative cropping systems: the need for greater management skills, the risks of lower yields and profits, increased weed problems, and constraints in federal programs. Single copies of the report are free from the U.S. General Accounting Office, P.O. Box 6015, Gaithersburg, MD 20877; (202) 275-6241.

Half a Glass of Water: State Economic Development Policies and the Small Agricultural Communities of the Middle Border, by Marty Strange, is a 132-page report on economic development policies of 277 counties in Iowa, Kansas, Minnesota, Nebraska, North Dakota, and South Dakota. Copies are $8 postpaid from the Center for Rural Affairs, P.O. Box 405, Walthill, NE 68067 (Nebraska residents add 32 cents tax).

A New Lease on Farmland: Assuring a Future for Farming in the Northeast is a 28-page booklet from the E. F. Schumacher Society. It discusses the interaction of conservation land trusts with farmers in management of protected lands. For information, contact the E. F. Schumacher Society, Box 76A, RD 3, Great Barrington, MA 01230.

Equipping for Maximum Net Forage Production is a 33-minute video about Voisin grazing management from the University of Vermont. It covers fencing and drinking water equipment and pasture mass relationships that influence the amount of forage harvested by grazing livestock. The video is $15 postpaid (payable to the University of Vermont) from Bill Murphy, Department of Plant and Soil Science, Hills Building, University of Vermont, Burlington, VT 05405.

Agroecology and Rural Development in Latin America is a videotaped lecture by Miguel A. Altieri of the University of California, Berkeley. It gives a slide-illustrated analysis of socioeconomic and agroecological constraints facing peasants and the efforts of local non-governmental organizations to help. The video is $35 from Agroecology, 1050 San Pablo Avenue, Albany, CA 94706.

The Portable Symposium is a guide to international agricultural trade issues, including ideas before member nations of the General Agreement on Tariffs and Trade (GATT). The guide includes papers and workshop discussion ideas for rural groups. It is $6 from the Center for Rural Affairs, P.O. Box 405, Walthill, NE 68067.

The Gene Exchange, a new newsletter from the National Wildlife Federation, provides information on developments in genetic engineering, including agricultural applications. It is free from the National Biotechnology Policy Center, the NWF, 1400 - 16th Street, NW, Washington, DC 20036-2266.

Agri-Balance, a slide show turned into a video, portrays the assets of organic farming. For information on this and six other videos, contact John Hughes, Shoestring Productions, 9559 State Route #28, New Vienna, OH 45159.

1989 Illinois On-Farm Demonstration Project reports the results of 12 on-farm demonstrations of low-input, sustainable farming methods. For copies, contact the Midwest Regional Office, American Farmland Trust, 407 South Dearborn, Suite 1550, Chicago, IL 60605.

Exploring the Linkages is a study kit on the connections between trade policies, Third World development, and U.S. agriculture. *Linkages* is a 14-minute video on the topic. Both were developed by the Trade and Development Program, a project sponsored by multiple churches, for use with farm, church, or community discussions. The study kit is $5 (plus $2 shipping); study booklets for participants are $3.50; and the video is $10 (plus $2 shipping). Order from the Trade and Development Program, 802 Rhode Island Avenue, NE, Washington, DC 20018.

LISA Apple Project tests lower-chemical production

Even with IPM practices in use, most Northeast apple growers still spray insecticides about seven times, fungicides about nine times, and acaricides about three times, say leaders of the Northeast LISA Apple Project. Because disease-resistant cultivars may solve some problems, the University of Massachusetts is evaluating ideal harvest dates and storage life of such apples. UM researchers are also surveying National Parks for "antique" cultivars that might have special genetic resources. Cornell University is comparing the economics of conventional and low-input production, and the Rodale Research Center is testing floral interplantings to see if insect-attracting plants decrease fruit damage.

The *Northeast LISA Apple Newsletter* publishes information from the 5-state cooperating groups. For information, contact Editor Daniel Cooley, Department of Plant Pathology, Fernald Hall, University of Massachusetts, Amherst, MA 01003.

Effects of conversion to organic agricultural practices on soil biota

Matthew R. Werner and Daniel L. Dindal

Abstract. *In the fifth year of an agricultural conversion experiment in Pennsylvania, we studied the soil biological community under three treatment regimes planted with corn: organic-manure, organic-legume, and a conventional system. The organic treatments consisted of complex crop rotations, cultivations, and organic matter inputs to control pests and maintain soil fertility. The conventional system consisted of a simple corn/soybean rotation with synthetic fertilizer and pesticide inputs. High rates of CO_2 evolution (a measure of potential microbial activity) in the organic plots corresponded with high levels of organic matter input. Soil nematodes were most abundant in organic plots, although seasonal patterns differed between the two organic treatments. Soil microarthropods were dominated by fungivorous Prostigmata mites, which reached peak abundance in organic plots two to five months after organic matter incorporation. Oribatid mites, which were rare throughout the study, followed the same pattern of abundance in each treatment and were probably most influenced by tillage disturbances. Predatory Mesostigmata were generally more abundant in organic plots. Surface-dwelling Collembola were abundant briefly in the spring, but soil-dwelling species dominated numerically throughout the cropping season. Spring tillage appeared to have a strong negative effect on earthworm populations in all plots. Small earthworm species became abundant in organic-manure plots during the summer. Larger earthworm species were abundant in organic-legume and conventional plots after the autumn harvest, when crop residues covered the undisturbed soil. The systems-level nature of the Conversion Project experiment makes it difficult to identify cause-effect relationships. The data do suggest that organic amendments tend to enhance soil biological activity, while tillage disturbances tend to disrupt the biotic community.*

Key words: organic soil amendments, tillage, soil respiration, nematodes, microarthropods, collembola, mites, earthworms

Introduction

Soil biota are likely to be of increased importance in agricultural systems where synthetic fertilizers are replaced by organic amendments and cultural practices (organic systems). Nutrients from organic sources become available through the interactions of biologically based nutrient cycling processes, especially organic matter mineralization and nutrient immobilization (Radke et al., 1988). A model for nutrient availability in organic systems should place less emphasis on increasing absolute nutrient inputs and focus more on intensifying nutrient cycling (Patriquin, 1986). This implies developing a greater understanding of how management effects soil biological processes (Doran and Werner, 1990; Kladivko and Timmenga, 1990).

In 1985, we studied a variety of soil biological parameters in conjunction with the Rodale Research Center's (RRC) Conversion Project. A primary objective of the Conversion Project, which was started in 1981, was to explore ways of avoiding lowered crop yields which are typical during the first three to five years after farmers make the initial transition to organic methods (U.S. Department of Agriculture, 1980). The objective of the present study was to characterize and compare the belowground community through a cropping season in the three management regimes of the Conversion Project. We hypothesized that in the fifth year after conversion to organic methods significant differences in soil biotic community structure would be apparent when comparing the three systems, due to the different cultural practices used.

Organisms and processes studied

The following is a brief introduction to the organisms and biological processes studied, including microbial respiration, nematodes, microarthropods, and earthworms.

Most soil microorganisms are primary decomposers, and the microbial community is generally responsible for 90 percent or more of the total energy flow through soil ecosystems (Coleman and Sasson, 1978). Primary decomposers break down organic and some inorganic substrates, releasing energy and nutrients through enzyme mediated metabolic systems. A major byproduct of much of this respiratory metabolism is carbon dioxide (CO_2). The measurement of CO_2 evolution is a direct indication of microbial activity (Singh, 1977) and an indirect indication of available organic matter levels in soils (Macfadyen, 1971).

Nematodes have a well-deserved reputation as parasites of plant roots. However, the majority of soil-dwelling species participate in decomposition processes (Freckman and Caswell,

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1985). Some species feed directly on decaying residues, while others form important trophic (food web) links between microbes (bacteria, protozoans) and other soil invertebrates (Ingham et al., 1986). Non-parasitic nematodes become abundant in agroecosystems when soil organic matter levels are high (Van Gundy and Freckman, 1977; Yeates, 1979).

Microarthropods make up a large and functionally important part of the soil ecosystem. They influence microbes, nematodes, and other soil microinvertebrates by direct and selective feeding, by incorporating modified substrates into the soil matrix, and by inoculating fresh residues with microbes (Werner and Dindal, 1987). Mites (Acari) and springtails (Collembola) are the dominant groups, commonly numbering 10,000 to 100,000 individuals per square meter of soil (Petersen and Luxton, 1982). Four mite suborders are usually represented in temperate soils: Oribatida, Prostigmata, Mesostigmata, and Astigmata.

Oribatid mites dominate in undisturbed ecosystems (Norton, 1985). They are slow-moving, heavily sclerotized mites that feed predominantly on decomposer microorganisms and decaying organic residues. In disturbed soils, oribatids are typically replaced by prostigmatid mites. Prostigmata is an extremely diverse group of animals that in addition to saprophages (feeders on decaying organic matter) includes predators, parasites, and phytophages (Kethley, 1990). Because the two groups respond oppositely to disturbance, the ratio of oribatids to prostigmatids (O/P) has been used as an index of soil ecological development (Loots and Ryke, 1967). Prostigmatids reproduce rapidly and are able to respond quickly to temporary food increases, even in highly disturbed soils (Norton, 1985). Oribatids have longer generation times, and most species are negatively effected by disturbance. The O/P ratio typically falls below 1 in agricultural soils and above 1 in more stable ecosystems (Table 1).

Most soil-dwelling mesostigmatid mites are predators on small invertebrates. One subgroup, the uropodines, specializes as fungivores. Small predatory species, adapted to life in deeper layers of mineral soil with small pore spaces (Walter, 1987), often dominate in disturbed soils. Larger species are included in the mesostigmatid community as organic surface layers increase the structural complexity of the soil ecosystem (Whelan, 1978; Sheals, 1956). Astigmatid mites occur in relatively low densities. They are generally saprophages and tolerant of high moisture conditions. Some feed on plant roots. Soil collembolans (springtails) feed on bacteria, fungi, algae, organic residues, and arthropod feces (Christiansen, 1964). They also are important prey for many soil predators.

Earthworms in the northeastern United States are almost exclusively members of the family Lumbricidae, introduced from Europe (Gates, 1970).

Table 1. Oribatida/Prostigmata ratios in different habitats.

Ratio	Habitat	Source
0.02	corn, sandy soil	Loots and Ryke, 1967
0.2	corn	Moore *et al.*, 1984
0.2-0.6	conventional tillage, different crops	House and Parmalee, 1985
0.45	second year pasture	Whelan, 1978
0.5-1.1	no-tillage, different crops	House and Parmalee, 1985
0.7-1.6	burned prairie	Seastedt, 1984
1.3	grazed grassland	Curry, 1969
1.5-2.3	unburned prairie	Seastedt, 1984
1.7	Beech wood	Luxton, 1982
1.7	Scots Pine forest	Persson *et al.*, 1980
3.0	forest (Africa)	Loots and Ryke, 1967
4.8	permanent pasture	Whelan, 1978
4.9	Aspen woodland	Mitchell, 1977

Table 2. Conversion Project history of field operations in plots planted to corn during 1985.

Month	Organic-Manure	Organic-Legume	Conventional
MAR	-manure -disk -plow		-disk -plow
APR	-disk -cultipak 2X -corn planted		-disk -cultipak 2X -corn planted -fertilizer -herbicide
MAY	-rotary hoe 2X	-vetch mowed and plowed -cultipak -corn planted -rotary hoe 2X	
JUN	-cultivated 3X	-cultivated 3X	-NH_4NO_3 side dressing
JUL			
AUG			
SEP	-silage harvest		
OCT	-plow -cultipak 2X -wheat planted		
		-grain harvest	
NOV		-residue mowed	-grain harvest -residues mowed

Table 3. Previous rotation histories in Conversion Project plots studied. 'A' is organic with animal manure, 'B' is organic with legume green manure, and 'C' is a conventional cash grain system. All plots were planted with corn in 1985.

1981	1982	1983	1984
A spring oats, red clover	red clover	corn-grain	soybeans-grain
B soybeans-grain	spring oats, red clover	corn	wheat-grain, hairy vetch
C soybeans-grain	corn-grain	corn-grain	soybeans-grain

Many species in this family are adapted for life in disturbed soils and thrive in human-populated areas. Earthworms play major roles in organic matter decomposition, the maintenance of soil fertility, the formation of soil structure, and horizonation (Kladivko and Timmenga, 1990). Three ecological types are recognized. Epigeic species dwell in organic horizons and ingest large amounts of undecomposed litter. Endogeic species dwell in the mineral soil and ingest soil rich in organic matter. Both of these types form impermanent burrows. Anecic species build permanent, vertical burrows and drag organic litter from the surface down into their burrows before ingesting it (Lee, 1985).

Methods

A replicated experiment was established on a 6 hectare field in east-central Pennsylvania (Berks County), where the climate is moderate, humid, and continental. The field had previously been farmed conventionally for corn and wheat production. The soil was primarily Comly silt loam, on a 3 percent slope. Our work in 1985 focused on soils cropped with corn and compared three different agricultural treatments. Two treatments represented organic systems, one with animal manures (organic-manure) and one with legumes plowed under as a green manure (organic-legume); the third treatment was a conventional system with synthetic fertilizer and pesticide applications. See Table 2 for a schedule of field operations in the three treatments and Table 3 for crop rotation histories in the plots studied. Further details and other aspects of the Conversion Project are reported in Liebhardt et al. (1989), Culik (1983), Doran et al. (1987), and Werner (1987).

We sampled monthly from May through November, 1985. The Conversion Project was designed as a split-plot randomized block with eight replications. Two samples from each of four plots gave a total of eight samples per treatment for each sample date. Samples were collected from random locations within the middle rows of each plot. Soil samples were stored in sealed plastic bags and placed in a cooler for transport to the laboratory for analyses.

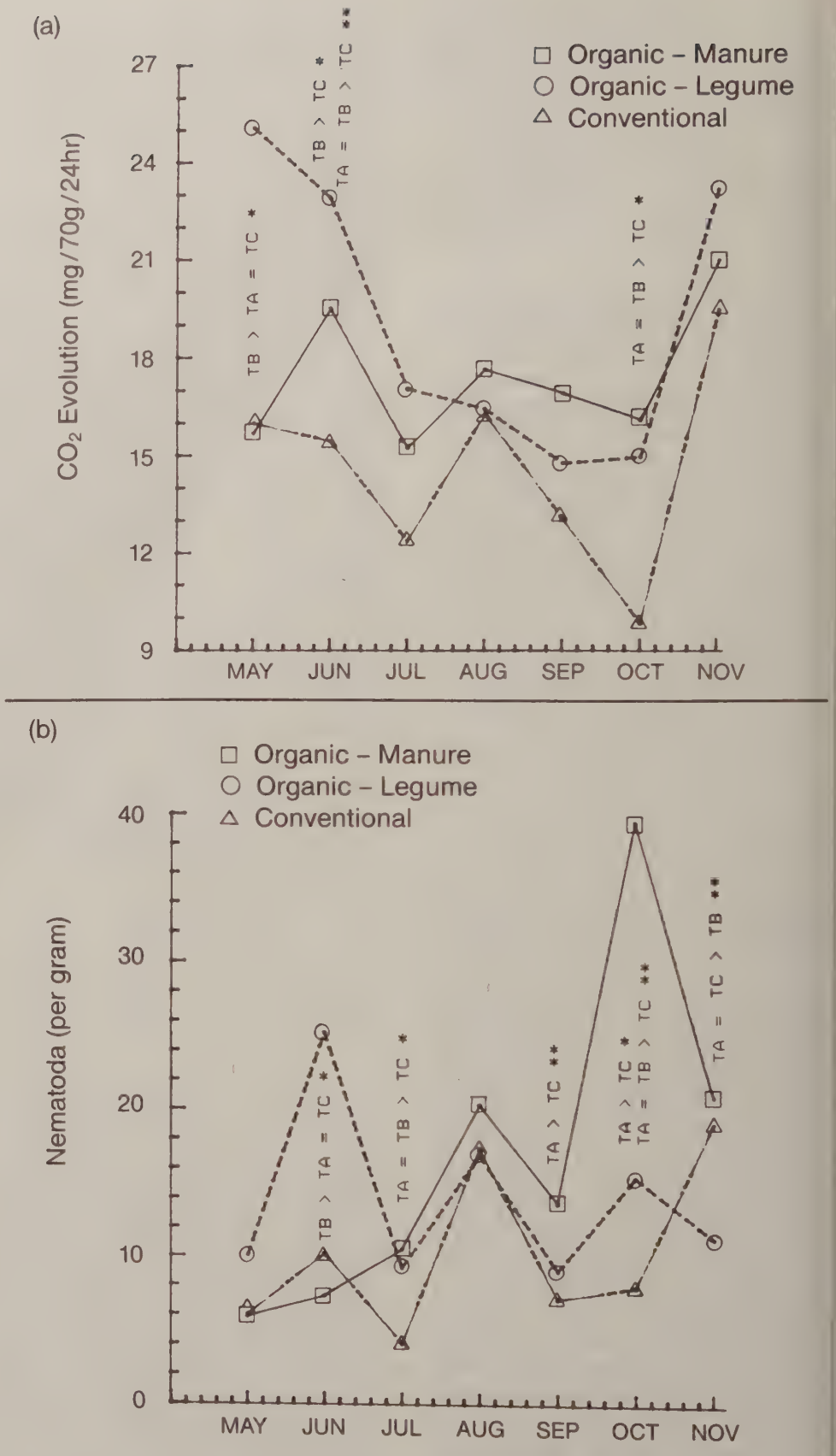


Figure 1. Mean CO_2 evolution from rewetted soils (a) and nematode abundance (b) in the Conversion Project. Statistically significant differences based on Tukey's multiple means comparison are noted at 2 levels: *, $\alpha = .05$; **$\alpha = .10$. Data logarithmically transformed prior to ANOVA. TA, TB, and TC designate organic manure, organic legume, and conventional treatments, respectively, for figures one through six.

Estimates of CO_2 evolution *in situ* include contributions from plant roots as well as from microbes, plus minor contributions from soil invertebrates. Measurements on samples that were dried and later rewetted in the laboratory remove plant and invertebrate influences, as well as the influence of temperature and moisture fluctuations. Carbon dioxide evolution from rewetted soils provides a measure of potential microbiotic activity and is directly related to the abundance of viable microbial propagules and the amount of stored and available energy in the soil.

To measure microbial respiration, 70 g (dry wt) soil samples were placed in glass jars and rewetted to 70 percent of water-holding capacity. Carbon dioxide was collected in 10 ml of 0.6N NaOH for 24 hours at 21°C in the dark. Titration with 0.1N HCl determined the amount of CO_2 evolved (Anderson, 1982). Water-holding capacity (Klute, 1965) was determined by placing 50 g of soil in a glass column open at both ends and supported over a sieve and adding 50 ml of water. Water draining from the soil was collected for 30 minutes. Water-holding capacity was calculated as the difference between water added and water draining.

Nematodes were sampled using 2 cm by 5 cm deep soil cores. Subsamples of 2 to 3 g were extracted using the Baermann funnel technique (Oostenbrink, 1971). The soil subsamples were dried and weighed, and nematodes were counted and expressed as total number per gram of dry soil.

Soil microarthropods were extracted from 5 cm by 5 cm deep soil cores using Tullgren funnels and collected in alcohol-water-glycerol preservative (Edwards and Fletcher, 1971). Mites and collembolans were preserved on glass slide mounts for counting and identification.

Earthworms were sampled monthly using the dilute formalin expulsion method (Satchell, 1971). A plastic ring (30 cm diameter) was sunk part way in the ground, and 4.5 l of a 0.4 percent formalin solution poured slowly into the ring. All earthworms rising to the surface within 10 minutes after complete infiltration were taken as the sample. Since this method does not obtain quiescent individuals, or those dwelling deep in the soil, it provides a relative estimate of earthworm activity and abundance. Earthworms were stored in 10 percent formalin for subsequent identification.

To sample soil moisture, 5 by 5 cm cores were collected, stored in plastic bags, weighed fresh, oven dried at 100°C overnight, and weighed dry. Soil moisture was expressed as a percentage of soil dry weight. Weekly rainfall data were collected by RRC staff.

Results and discussion

Carbon dioxide evolution was greater from organic-legume plots than from conventional soils in May and June (Figure 1.a). A vetch green manure crop was incorporated into the organic-legume plots in early May, and the high level of microbiological activity in soils from these plots suggests mineralization of the vetch residues. Microbes are often more abundant in soils with organic amendments (Fraser et al., 1988; Martyniuk and Wagner, 1978). However, respiration rates from organic-manure soils were not as high as from organic-legume soils during this period. Ammonium nitrate was added as a sidedressing (123 kg-N/ha) to conventional plots in June, and rates of CO_2 evolution decreased in July samples from these plots. Mineral nitrogen does not provide an energy source for most soil microbes and may also have some inhibitory effects (Sod-

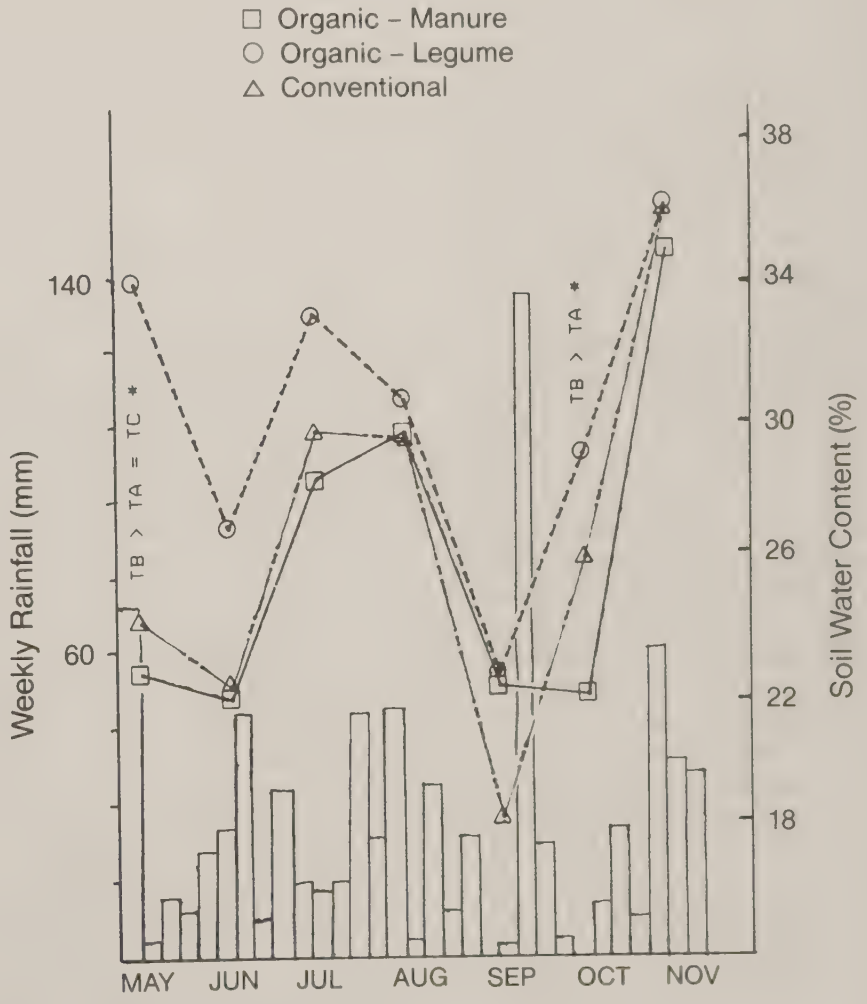


Figure 2. Monthly soil moisture content of study plots overlayed on a weekly rainfall histogram. Statistically significant differences in soil moisture content ($\alpha = .05$) based on Tukey's multiple means comparison are noted.

erstrom et al., 1983).

It is unclear why microbial respiration rates dropped so sharply in the conventional plot samples during October, although dry soil conditions in all plots during September (Figure 2) may have decreased microbial populations. Increases in all plots during November coincided with residue inputs after crop harvest.

Nematodes were more abundant in the organic-manure treatment in July, September, and October, while the organic-legume treatment produced statistically greater abundance in June and July (Figure 1.b), relative to the conventional treatment. As with microorganisms, nematode abundance reflects the amount of available carbon present in the soil. Important carbon sources include animal and green manures, crop residues, and root exudates (Freckman and Caswell, 1985). Incorporated vetch in the organic-legume plots provided a potential substrate that may have allowed nematodes to increase in June and July. Weed biomass was greatest in organic-manure plots (Liebhardt et al., 1989), especially later in the season, and root exudates were a possible factor leading to increased nematode abundance in these soils.

Mites, which were the most abundant group of microarthropods, were dominated by prostigmatids (Figure 3.a). Prostigmatids appeared to respond positively to the incorporation of organic residues, with saprophagous species dominating. The peak during June in conventional plots was caused by one very large aggregation of pygmephorid mites (*Pseudopygmephorus*). Large aggregations are common at concentrated carbon sources, such as vertebrate dung or an invertebrate carcass (Usher et al., 1982). The mean of 7 remaining samples from conventional plots in June, which is marked with a dot in Figure 3.a, falls more in line with samples from other months.

The different abundance patterns of saprophagous prostigmatids in both organic treatments may be a reflection of different management techniques. In both cases, increases of prostigmatids follow by 2 or 3 months the incorporation of organic materials. In plots with

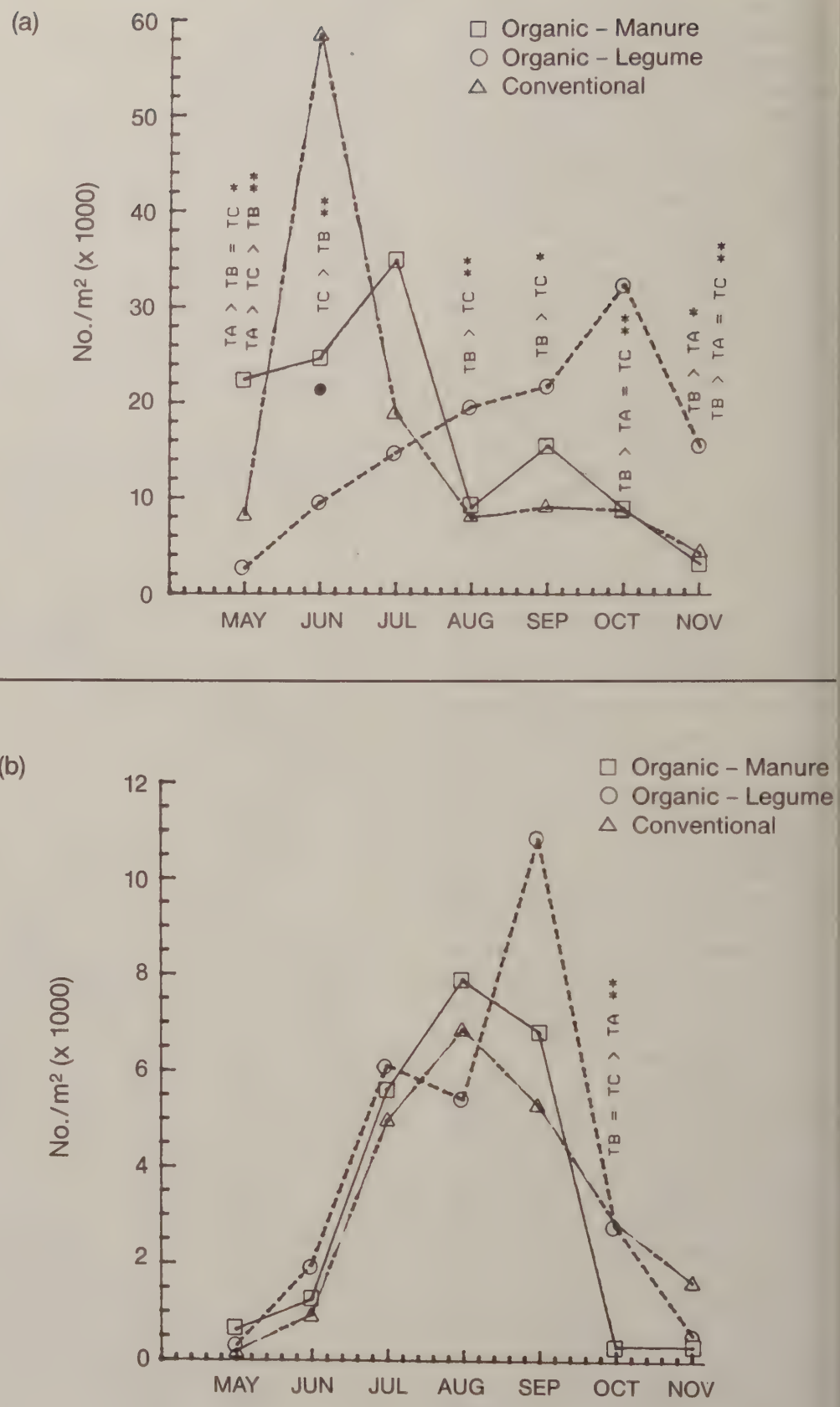


Figure 3. Mean estimates of Prostigmata (a) and Oribatida (b) abundance in Conversion Project soils. Statistically significant differences based on Tukey's multiple means comparison are noted at 2 levels: *, $\alpha = .05$; **, $\alpha = .10$. Data logarithmically transformed prior to ANOVA. Dot on Figure 3.a. shows mean of 7 samples from conventional plots, excluding 1 sample with a large aggregation of pygmephorid mites.

manure plowed into the soil in March, prostigmatid abundance peaked in May to July. Vetch was plowed under in organic-legume plots in early May, and the prostigmatid response occurred in August through October. These mites may have been involved in the release of nutrients from organic amendments. Prostigmatid densities were generally lower in conventional treatment soils.

Density of oribatid mites did not differ significantly between the three treatments (Figure 3.b). This pattern of a single abundance peak during the summer is atypical of oribatids, which are generally more active during spring and autumn in undisturbed temperate soils (Norton, 1985). The one management technique common to all treatments and probably responsible for this atypical response was tillage. All plots were moldboard plowed in the spring, strongly suppressing oribatid populations. Autumn plowing in organic-manure plots, prior to winter wheat planting, had the same suppressive effect.

We explored the oribatid/prostigmatid mite ratio for indications of greater soil successional development under organic management techniques. The index fell within the range common to agricultural soils (Figure 4; compare with Table 1), and only in June was there a treatment difference that was statistically significant. The greater mean values for conventional plots during October and November were due not to an increase in oribatids, but to a greater decrease of prostigmatids relative to organic treatments. This suggests that moldboard plowing had a strong disturbance effect that did not allow soil successional development or differentiation.

As predators, mesostigmatid mites are important regulators of soil invertebrate populations and thus influence decomposition rates and nutrient cycling (Coleman, 1985). Above-ground species have been successfully used as biocontrol agents for plant pests (Oatman et al., 1968), and soil species may potentially play the same role with below-ground pests (Buhlmann, 1984). Mesostigmatids were most abundant in organic-manure plots; statistically greater means relative to conventional plots occurred during May, September, and October (Figure 5.a).

Weed growth may have influenced differences in mesostigmatid mite densities between treatments. Weed biomass was significantly greater in the organic-manure treatment than in the organic-legume and conventional systems (Liebhardt et al., 1989). In the treatments with less weed growth, mesostigmatid abundance dropped off during the summer, while in the organic-manure treatment, mesostigmatids maintained larger populations through the season. Weeds, besides being competitors for crop growth requirements, may have beneficial effects on soil ecological processes. Weeds shade the soil surface and create a more moderate microclimate. They also add litter, root exudates, and other residues to the soils, creating a structurally and chemically diverse microhabitat. This may explain increased mesostigmatid abundance in the manured plots.

Very few astigmatid mites were collected, and most were in a non-feeding growth stage called a hypopus. Therefore, astigmatids were of minor importance in Conversion Project soils.

Conversion to organic management practices led to increases in Collembola abundance during portions of the season (Figure 5.b). Statistically significant increases occurred in the organic-manure plots in September and in the organic-legume plots in June and October. Increases of collembolans appear to be related to organic matter inputs, a relationship not seen with synthetic fertilizers. Addition of ammonium nitrate during June corresponded to a decrease of collembolans in the conventional treatment plots. The sharp drop in abundance in organic-manure plots from September to October corresponds to harvest and seed bed preparation in these plots.

The earthworm community was composed of two anecic species (*Lumbricus terrestris*, and *Aporrectodea longa*) and three endogeic species (*A. turgida*, *A. trapezoides*, and *A. tuberculata*). Epigeic species are strongly affected by tillage

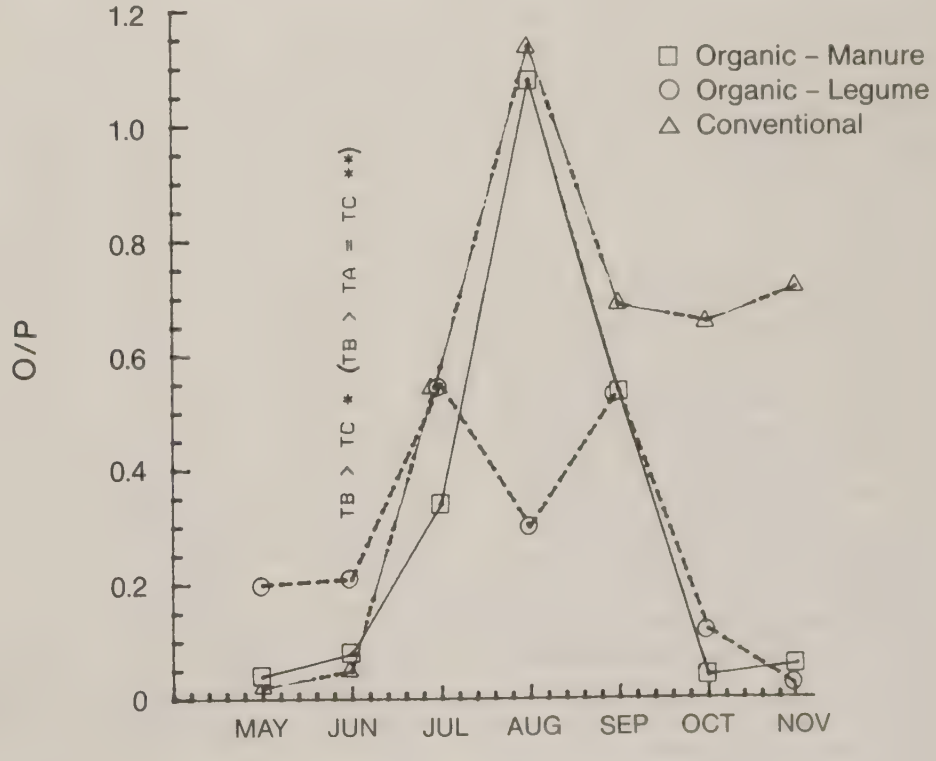


Figure 4. Average Oribatida/Prostigmata ratios in Conversion Project plots. Statistically significant differences based on Tukey's multiple means comparison are noted at 2 levels: *, $\alpha = .05$; **, $\alpha = .10$. Data logarithmically transformed prior to ANOVA.

and the loss of an organic surface layer, and none were found in this study.

Earthworm activity was low to absent from May to July (Figure 6.a). Rodale Research Center staff observed that earthworms were abundant at the time of green manure incorporation in organic-legume plots. Tillage may have killed them or caused them to retreat to deeper soil horizons.

In August and September earthworms were most abundant in the organic-manure plots. Earthworms active at this time were mainly small endogeic species, which may have responded to manure addition or to organic inputs from weed roots. Low soil moisture during September (Figure 2) coincided with a decrease of earthworm activity in all plots. Harvest and planting operations in organic-manure plots during October caused further decreases of earthworm activity in these soils.

In contrast to organic-manure plots, which were harvested for silage, organic-legume and conventional plots were harvested for grain in November. The remaining crop residues were mowed and left on the soil surface. This provided an ideal habitat for large anecic species, which increased at this time (Figure 6.b). Soils unprotected by a surface mulch freeze faster than mulched soils, and earthworms die unless they can gradually adjust to decreasing temperatures (Slater and Hopp, 1947).

Conclusions

Our results show that, in the fifth year after conversion to organic methods of corn production, several groups of organisms were more abundant and more active during portions of the crop season. The broad, systems-level nature of the Conversion Project makes it difficult to identify causal relationships. Our interpretation is that additions of organic matter in any form, including animal manures, green manures, and crop and weed residues, can be beneficial because they supply a food resource to the detritus-based soil decomposer food web. Increasing the detritus resource has the potential for enhancing nutrient cycling processes. Soil tillage practices (plowing, cultivation) disturb or destroy

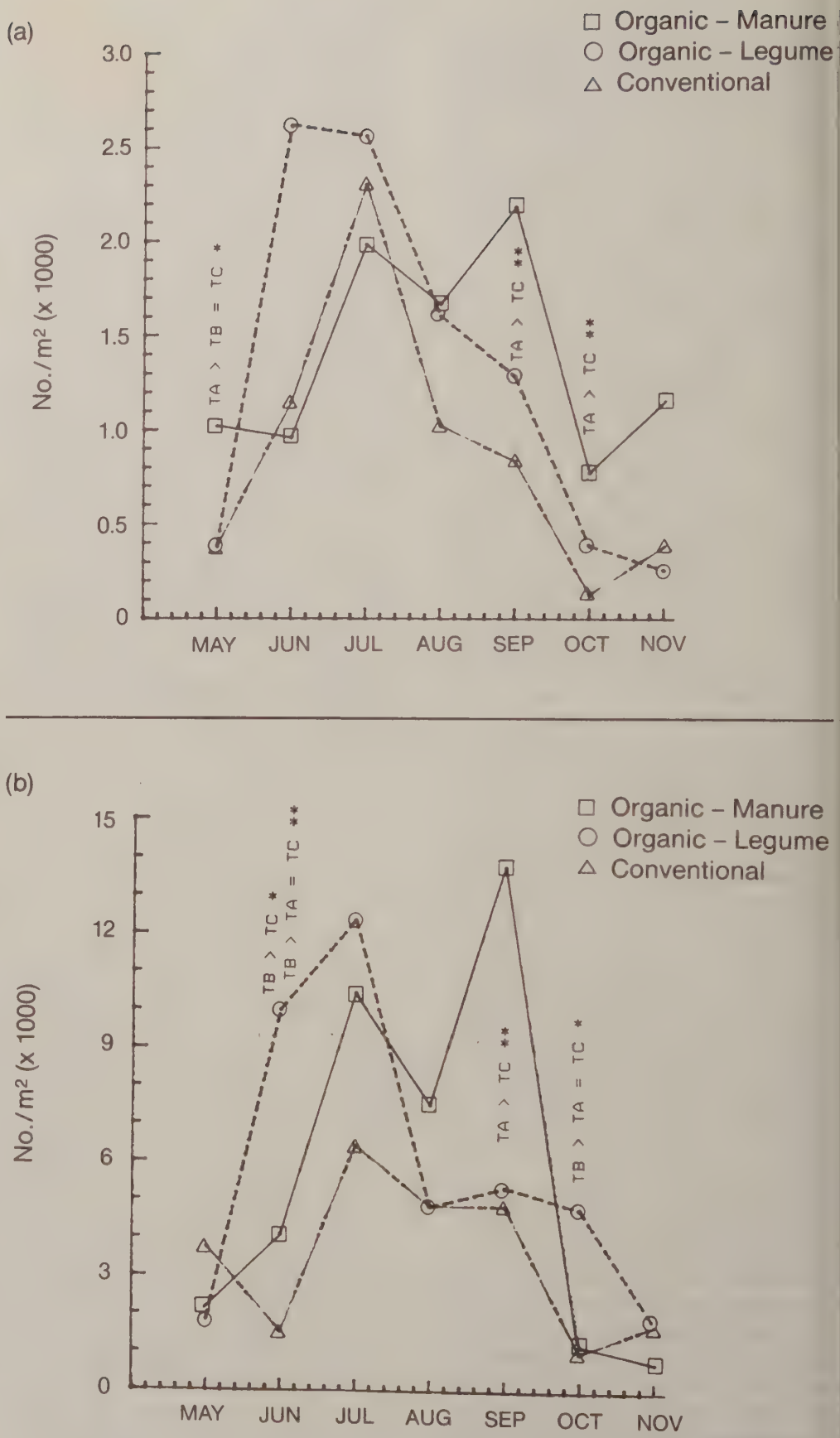
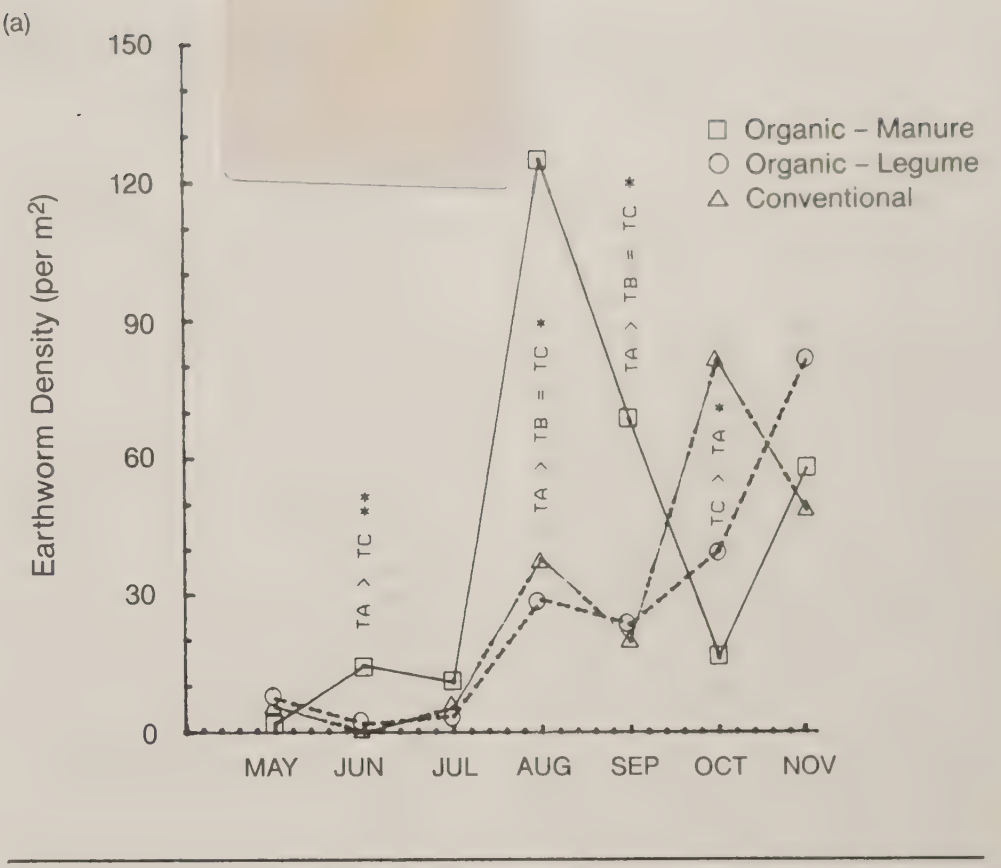


Figure 5. Mean estimates of Mesostigmata (a) and Collembola (b) abundance in Conversion Project soils. Statistically significant differences based on Tukey's multiple means comparison are noted at 2 levels: *, $\alpha = .05$; **, $\alpha = .10$. Data logarithmically transformed prior to ANOVA.

soil biota, especially invertebrates, and prevent colonization by species not adapted to disturbance. Indicators of ecological successional development, such as increased species diversity (Hendrix, 1987), are therefore severely limited in any agricultural system that uses conventional tillage. The benefits for soil biota of conversion to organic methods generally appear to be of a transient nature, although increased production of propagules and other dormant life stages after periods of enhanced activity could increase the long-term biological potential of soils for decomposition and efficient nutrient cycling.

Acknowledgments. This research was supported in part by a grant from the Rodale Research Center and by a fellowship to M.R.W. from the Roothbert Foundation. Soil ecology students at SUNY-CESF helped with field work and provided stimulating discussion. Steve Gliessman and Martha Rosemeyer at UCSC offered helpful criticisms of the manuscript.



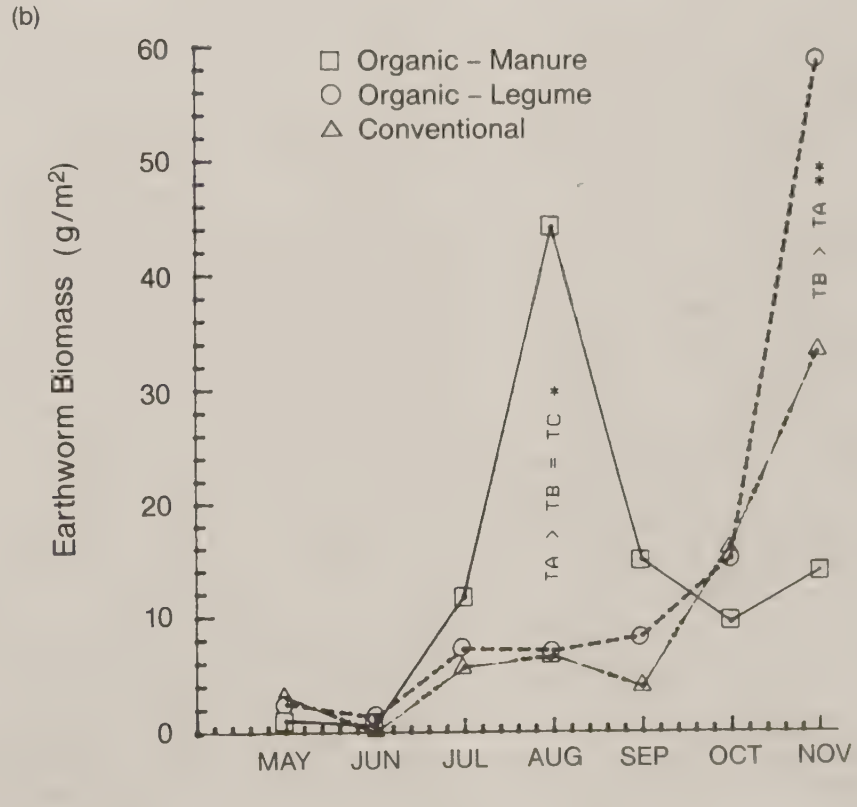


Figure 6. Mean estimates of earthworm density (a) and earthworm biomass (b) in Conversion Project soils. Statistically significant differences based on Tukey's multiple means comparison are noted at 2 levels: *, $\alpha = .05$; **, $\alpha = .10$. Data logarithmically transformed prior to ANOVA.

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Iowa project helps farmers cut fertilizer rates

In a joint project between Iowa State University and Iowa fertilizer dealers, nitrogen fertilizer rates were reduced by 62 percent on 23 Iowa corn fields in 1989. Sixteen fertilizer dealers, selected by the Iowa Fertilizer and Chemical Association, took soil samples on their customers' farms. ISU labs analyzed them for nitrogen needs, and the dealers then established replicated strip plots to compare the lower recommended rates with fields using the "regular" rates.

The average "regular" rate was 123 pounds of nitrogen per acre, giving a yield of 130 bushels of corn. The test-determined rate of nitrogen was 47 pounds per acre, and the average yield on those strips was 131 bushels per acre. ISU agronomist Alfred Blackmer, who developed the test, thinks it can help farmers cut fertilizer use by one-third, at an annual savings of $100 million for the state. The research was reported in the Winter 1990 issue of *Integrated Farm Management Notes* from Iowa State University, Ames, IA 50011.

Rainfall and previous crop effects on crop yields

Todd Andrews Peterson, Charles A. Shapiro, and A. Dale Flowerday

Abstract. *A field study was conducted between 1972 and 1982 to compare the effects of previous crop on row crop yields under rainfed conditions in eastern Nebraska. The objectives were to determine the effects of fallow and three previous crops: corn (*Zea mays*L.), soybeans [*Glycine max *(L.) Merr.], and grain sorghum [*Sorghum bicolor *(L.) Moench], on the growth and grain yield of the same crops. The study was conducted on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic, Typic Argiudoll). Corn grain yield was most variable (C.V. 23.4 percent) compared to soybean (C.V. 13.6 percent) or grain sorghum (C.V. 9.5 percent) yields. Corn was also the most sensitive crop to previous crop effects. The range of treatment yields for each crop was 47 percent, 22 percent, and 11 percent of the overall means for corn, soybean, and sorghum, respectively. Previous crop affected yields for all crops, but the effects were not consistent across years. All crops produced highest yield following fallow. Yields of corn, soybean, and grain sorghum following fallow were 74, 25, and 10 percent higher than their respective monoculture yields. In years of average precipitation, a corn-soybean sequence produced the greatest yield. In years having above- or below-normal precipitation, a grain sorghum-soybean sequence produced the highest yield.*

Key words: crop rotation, crop sequence, corn, soybean, grain sorghum

Introduction

The beneficial effects that specific crops have on the yields of subsequent crops were known even to the ancient Romans (White, 1970). With the development of agricultural chemicals following World War II, interest in crop rotations diminished. Chemical pesticides and fertilizers seemed to replace the benefits of rotating crops. Changes in the economics of crop production and recognition of the potential environmentally damaging effects of agricultural chemicals have led to renewed interest in sustainable production systems. These systems replace some purchased inputs, especially pesticides and fertilizers, with cultural practices, timeliness, and labor, and usually involve rotating crops.

Although more research is under way on why crop rotation influences yield of subsequent crops, producers can receive maximum benefit from rotating crops if they know the conditions that influence rotation effects. For example, knowledge of how precipitation influences the rotation effect, when combined with weather predictions and economic analysis, will enable producers to improve their crop selection decisions.

Previous research has investigated the beneficial effects of legumes on subsequent crops. These effects are often separated into nitrogen (N) effects from addition of symbiotically fixed N_2 and non-N effects, defined as the benefits of rotation besides the effects of added N (Baldock et al, 1981; Randall et al., 1985). Non-N effects occur when crop yields of continuous monocultures do not attain the yields of crops in rotation, even with the addition of high fertilizer N rates (Barber, 1972; Bolton et al., 1976; Carreker et al., 1972; Clegg, 1982; Higgs et al., 1976; Nafziger et al., 1984; Randall et al., 1985; Welch, 1976). Non-N rotation effects include changes in soil physical properties (Fahad et al., 1982), allelochemical (Crookston et al., 1988; Nafziger et al., 1984; Yakale and Cruse, 1984), and microbiological effects (Cook, 1984; Nafziger et al., 1984). Non-N rotation effects are generally difficult to explain using only the measurements commonly recorded in field studies (Crookston et al., 1988).

Corn response to fertilizer N differs with previous crop (Asghari and Hanson, 1984; Barber, 1972; Nafziger et al., 1984; Voss and Shrader, 1979; Welch, 1976). Nafziger et al. (1984) found that corn grown without fertilizer N following soybeans, oats (*Avena sativa* L.), alfalfa (*Medicago sativa* L.), and fallow produced yields equivalent to continuous corn fertilized with 73, 31, 121, and 64 kg N ha^{-1}, respectively. Olson et al. (1986) found that a winter cover crop of rye (*Secale cereale* L.) contributed a rotation effect by increasing yields in continuous corn. Beneficial effects of previous non-legume crops that do not contribute symbiotically fixed N to subsequent crops have also been reported from Minnesota and the Great Plains (Brown, 1964; Langer and Randall, 1981).

Precipitation often alters the effect of previous cropping history on subsequent crop yield (Barber, 1972; Brown, 1964; Carreker et al., 1972; Higgs et al., 1976; Kiesselbach and Lyness, 1952; Langer and Randall, 1981). A greater effect of

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previous crop on corn yields has been observed in dry years than in wet (Barber, 1972; Langer and Randall, 1981). Asghari and Hanson (1984) used regression analysis to relate corn N response to precipitation and temperature after two previous crops. They proposed a model of grain yield based on precipitation, heat unit accumulation during June and July, and grain N.

Rotation studies are long term since the effects of rotation must be documented over the range of possible weather conditions. The amount of precipitation in the growing season is important, particularly at the regional limits of crop adaptation, such as the western edge of the Corn Belt. The experiment reported here was initiated to determine the effects of previous crop on crop yield under varying rainfall conditions. The objectives of the study were:

1. to compare row-crop sequences including fallow to continuous monocultures of corn, soybeans, and grain sorghum in a rainfed cropping system;

2. to determine how growing season precipitation affects the response of current crop yield to previous crop.

Materials and methods

The experiment was established in 1972 at the University of Nebraska Agricultural Research and Development Center, near Mead, Nebraska. Soil at the site is a Sharpsburg silty clay loam (fine, montmorillonitic, mesic, Typic Argiudoll) with an organic matter content of 31 g kg^{-1} in the top 0.075 m. The experiment was a randomized complete block design with a factorial arrangement of treatment combinations. Factors were current crop and previous crop, with corn, soybean, grain sorghum, and fallow for both factors. All combinations of current crop and previous crop occurred in every year except continuous fallow, which was excluded from the design. Treatments were replicated four times except in 1973, when only three replicates were used. The fallow treatment was included in the design to answer questions from local producers who were considering government set-aside programs. Land involved in the acreage reduction programs at that time was often maintained as clean fallow. Subsequent government programs required maintaining a residue cover on idle land, so clean fallow was eliminated as a viable cropping alternative. Oats interseeded with yellow sweetclover (*Melilotus officianalis* L.) replaced fallow in the design in 1981; therefore, only previous crops of soybean, corn, and grain sorghum are used in the 1982 analysis. Data collection began in 1973. Each experimental unit was 9 m wide (12 0.76 m rows) and 30 m long.

Cultural practices, including weed and insect control, were similar to those used by local producers. Specific practices for the study are documented by McClure (1982). In late April or early May, crop residues from the previous corn and sorghum crops were shredded with a rotary mower. All plots were disked twice with a tandem disk and harrowed before planting. Plots were planted with a John Deere Flex 71 planter. Corn hybrid N7a x B73 was planted at approximately 46,000 seeds ha^{-1} during the first two weeks of May. Inoculated soybean (cv. Amsoy 71) and grain sorghum (hybrid NC+ 161) were planted during the last week of May or the first week of June. All plots were rotary hoed after crop emergence and

Table 1. Crop yield as affected by previous crop and year, showing seasonal rainfall total and analyses of variance on crop yield.

	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	Mean
Rainfall (mm) (5/1-9/30)	599	406	265	326	596	478	427	410	515	797	482
Rainfall class	wet	dry	dry	dry	wet	avg.	avg.	dry	avg.	wet	—
Grain sorghum yield following:	Mg ha^{-1}										
Fallow	7.15	4.20	3.67	6.56	6.58	5.87	7.00	5.98	6.76	4.95	5.96
Soybean	7.36	4.24	4.28	6.57	5.52	5.68	7.32	5.32	6.27	4.87	5.72
Corn	7.29	3.96	3.93	5.34	6.12	4.38	6.31	5.61	7.25	2.22	5.22
Sorghum	7.17	4.37	3.45	6.30	5.85	4.22	6.51	5.46	6.54	3.82	5.31
Mean	7.24	4.19	3.83	6.19	6.02	5.04	6.79	5.59	6.71	3.96	5.54
LSD 0.05	0.65	0.72	1.00	0.85	0.93	0.95	0.89	0.95	0.68	0.63	0.23
Pr > F due to Previous crop	0.77	0.64	0.33	0.03	0.14	0.01	0.11	0.09	0.05	***	***
C.V. (%)	4.2	10.8	16.3	8.6	9.6	11.7	8.2	10.3	6.4	10.0	9.5
Corn yield[&] following:	Mg ha^{-1}										
Fallow	6.69	0.11	3.67	3.09	3.56	7.82	6.10	4.28	6.75	4.19	5.14
Soybean	6.92	0.20	2.40	3.21	1.03	8.42	6.66	3.74	6.67	4.75	4.84
Corn	6.79	0.25	2.52	1.31	2.03	5.98	1.93	1.59	3.98	1.65	2.91
Sorghum	6.27	0.28	3.58	2.64	1.74	6.51	2.32	4.41	7.01	2.90	4.06
Mean	6.67	0.21	3.04	2.56	2.09	7.18	4.25	3.51	6.10	3.37	4.21
LSD 0.05	1.49	0.25	1.06	1.28	2.36	2.09	1.99	1.45	0.76	0.89	0.46
Pr > F due to Previous crop	0.34	0.19	0.04	0.03	0.17	0.09	0.01	0.01	***	***	***
C.V. (%)	11.6	10.2	21.6	31.2	70.5	18.1	29.2	26.1	7.8	17.5	23.4
Soybean yield following:	Mg ha^{-1}										
Fallow	2.83	2.74	2.16	1.51	2.34	2.48	1.76	2.15	3.55	2.49	2.36
Soybean	2.00	2.15	1.60	1.11	1.41	2.18	1.44	1.85	3.00	2.34	1.89
Corn	2.89	2.35	2.12	1.54	1.99	2.41	1.75	1.69	3.37	2.41	2.22
Sorghum	2.32	2.71	2.18	1.43	1.65	2.58	2.21	1.84	3.72	2.53	2.31
Mean	2.51	2.49	2.01	1.40	1.85	2.41	1.79	1.88	3.41	2.44	2.19
LSD 0.05	0.29	0.29	0.51	0.68	0.41	0.39	0.74	0.36	0.52	0.20	0.13
Pr > F due to Previous crop	0.00	0.00	0.03	0.49	0.00	0.18	0.18	0.10	0.05	0.11	0.00
C.V. (%)	5.7	7.2	15.7	30.2	13.9	10.1	25.8	12.8	9.5	4.7	13.6

[&] Corn yields from 1974 are not included in the mean values.
*** Indicates significant at less than 0.01 level of probability.

cultivated in mid or late June. Fallow plots were maintained free of weeds with a field cultivator, a 1.5-m V-blade sweep plow, or a tandem disk at 2-3 week intervals.

Fertilizer N was applied to all corn and grain sorghum plots as anhydrous ammonia side dressed (112 kg N ha^{-1}) following cultivation. Plots were harvested mechanically with combines modified for plot use. Yield data are reported at 155, 140, and 130 g H_20 kg^{-1} for corn, grain sorghum, and soybean, respectively.

Statistical analysis of crop yield data was performed for all crops and within each year to determine the effect of previous crop (Table 1). Error terms for soybeans and grain sorghum were homogeneous over years, so analysis of variance was conducted on the combined data (Table 2). For corn, error terms from 1974 and 1981 were not homogeneous with the other years. Corn yield data from 1974 were not included in the overall analysis because yields were extremely low from severe moisture stress during pollination. In 1981, corn yields were included in the overall analysis since the variation among plots was reduced compared to other years.

When combined over years, the year X previous crop effect on current crop yield was significant for all current crops and involved changes in rank of treatment means. To reduce the year X previous crop interaction, these data were divided into rainfall groups and analysis of variance was performed on each group (Table 2). Growing season rainfall (May 1-October 1) ranged from 265 mm in 1975 to 797 mm in 1982 with a mean of 482 mm. The 30-year precipitation average from May 1-October 1 was 464 mm. Years were classified as wet, average, and dry by forming an 80 percent confidence interval about the mean growing season rainfall (482 mm ± 56 mm). Using this classification, four years were considered dry years, three were considered average, and three years were considered wet (Table 1). Even after analysis of variance was performed for each crop within rainfall classes, there still was a significant year X treatment interaction. However, within each rainfall class, treatment means did not change rank.

Table 2. Analyses of variance on grain yield by rainfall class.

	RAINFALL CLASS		
	Wet	Avg.	Dry[&]
Grain sorghum			
Year	*	*	+
Previous crop	*	*	*
Continuous vs others	*	*	ns
Year x Prev. crop	*	*	*
Mean (Mg ha^{-1})	5.63	6.18	4.99
LSD 0.05 (Mg ha^{-1})	0.39	0.44	0.40
C.V. (%)	8.2	8.6	11.1
Corn			
Year	*	*	ns
Previous crop	*	*	*
Continuous vs others	*	*	*
Year x Prev. crop	*	ns	*
Mean (Mg ha^{-1})	3.65	5.85	3.03
LSD 0.05 (Mg ha^{-1})	0.92	0.90	0.67
C.V. (%)	29.6	18.4	26.2
Soybean			
Year	*	*	*
Previous crop	*	*	*
Continuous vs others	*	*	*
Year x Prev. crop	*	ns	ns
Mean (Mg ha^{-1})	2.23	2.54	1.91
LSD 0.05 (Mg ha^{-1})	0.17	0.30	0.22
C.V. (%)	8.8	14.0	15.7

"+" and "*" denote significant effects at the 0.10 and 0.05 probability level, respectively.
[&] Corn yields from 1974 are not included in the analysis of variance over years due to non-homogenous error variances.

Results and discussion

There was no one "best" crop sequence. In order to understand the variation from year to year, these data were divided into three rainfall classes: wet, average, and dry. Although this did not eliminate all year X previous crop interactions, treatment rankings did not change within rainfall classes, so we were able to evaluate and interpret the treatments over years within each rainfall class.

In all rainfall classes and for all crops, yields following fallow were consistently greater than or equal to any other previous cropping treatment (Table 2); but because of economic and environmental considerations, clean fallow is not a recommended option. Continuous monocultures produced consistently lower yields than rotated crops in all precipitation classes except for grain sorghum under dry conditions (Table 2). Crop yields and previous crop effects within a specific rainfall class will be discussed for each crop.

Corn

Of the three crops studied, corn was most sensitive to the effects of previous crop and climate. The two error variances that were not homogeneous (1974 and 1981) are evidence of this year-to-year variability. Producers using sustainable agriculture systems may consider limiting the area they devote to corn production because of its high input requirements and variable yields. Over the study period, corn yields ranged from almost no yield to over 7 Mg ha^{-1}. The percent yield range due to previous crop was the difference between the largest and the smallest yield, divided by the overall mean. When all years of the experiment

were combined, the range of corn yields was 47 percent of the grand mean. Regardless of rainfall class, corn produced maximum grain yield when following soybean and the lowest yield when following itself (Table 2). In dry years, corn yields following soybean or following grain sorghum were similar.

Soybean

Continuous soybean produced lower seed yield than other treatments in all rainfall classes. In dry years, soybean produced similar yields following grain sorghum or following corn. In average years, soybean following grain sorghum produced greater yield than when following corn (Table 2). In wet years, soybean yield was greater following corn than following grain sorghum. Based on coefficients of variation (C.V.), the variability of soybean yield due to previous crop was intermediate between corn and grain sorghum. The overall treatment yield mean as a percent of the grand mean was 22.6 percent for soybeans.

Grain sorghum

Grain sorghum yields were more stable across years and previous cropping treatments than either corn or soybean, as shown by the lower C.V.'s for grain sorghum in each rainfall class (Table 2). The range of the overall treatment yield means as a percent of the grand mean was 11.4 percent for sorghum. Increased growing season precipitation tended to increase the effect of previous crop on grain sorghum yield. Grain sorghum following fallow or soybean consistently yielded more than following grain sorghum or corn. In dry years, yield differences due to previous crop were small. In average years, continuous grain sorghum produced less grain than other treatments. In wet years, grain sorghum yield following corn was less than following other crops.

These data show that grain production in wet years was not increased compared to average years. Factors other than seasonal rainfall determined or limited final grain yield in wet years. Such factors may include temperature, disease, nutrient deficiencies, delayed field operations, subsoil moisture, rainfall distribution, and related environmental effects. Rainfall at the wrong time can delay timely field operations. For example, in 1982 rainfall during May delayed planting, which resulted in decreased grain yield.

Recommendations

A recommendation of the most profitable cropping sequence is beyond the scope of this paper. Such recommendations must result from an economic analysis of net returns, since production costs vary among crops. It is not possible to compare yields of different crops directly. Net returns to the producer should be used instead of crop yields to evaluate different crop sequences. An economic analysis should also include results from other rotation experiments that include close-seeded crops, such as small grains, forages, green manure, and cover crops. Agricultural climatologists may also find these data useful to compare crop yields when using historical weather patterns to predict the probability future crop yields.

Despite the lack of a direct comparison among crop yields, it is possible to recommend a row crop to follow corn, sorghum, or soybean, especially if one was willing to predict the coming seasonal rainfall. It has been proposed that rainfall in the midwest is cyclical (Thompson, 1988). Although exact seasonal rainfall cannot be predicted, dry or wet trends may be useful in planning the coming year's crops. Decision criteria for choosing a given crop sequence over another include yield potential, anticipated costs and economic returns, farm enterprise requirements, and tolerance or aversion to risk. Within a sustainable agricultural system, a producer might opt for a crop such as grain sorghum, which consistently produces relatively high grain yields, in place of a potentially higher yielding but more variable (or risky) crop such as corn. The relationship among these crop sequences establishes a framework for future crop selection (Table 3).

An example in Table 3 will demonstrate the utility of these data. Reading across the first line of Table 3, one can make the following statement: In dry years soybean following grain sorghum would give the greatest yield. Soybean following corn would yield 94 percent of that following sorghum, whereas continuous soybean would produce 82 percent of the yield of soybean following grain sorghum in a dry year. However, in wet years soybean following corn would yield the most (100 percent) and soybean following grain sorghum or soybean would yield 90 percent and 80 percent, respectively. If one does not wish to spec-

Table 3. Cropping system decision chart describing the relationship between previous crop and predicted response of future crops according to expected rainfall.

		Previous Crop		
		A field containing one of these previous crops would be expected to produce the following percent yield of the highest-yielding crop sequence.		
Potential Crop Choice	Expected relative rainfall	Sorghum	Corn	Soybean
		%		
Soybean	Dry	100	94	82
	Average	100	88	78
	Wet	90	100	80
Sorghum	Dry	94	93	100
	Average	90	93	100
	Wet	95	87	100
Corn	Dry	100	51	89
	Average	59	52	100
	Wet	81	73	100

Note: Read percentages across table only, see text for example.

ulate on seasonal rainfall, the yield means from Table 1 show that soybean on average produces the highest yields when it follows grain sorghum.

Our results confirm that the popular corn-soybean sequence produces higher yields for both crops than when either is grown continuously (Carreker et al., 1972; Crookston et al., 1988; Higgs et al., 1976; Voss and Shrader, 1979). The advantage of the corn-soybean rotation is particularly apparent in years of average precipitation, when corn produces much greater yields following soybean than following other crops. Soybean produces higher yields following corn in wet years, but in dry or average years it produces its highest yield following grain sorghum.

Summary

When producers follow sustainable agriculture principles, factors other than maximum yield are important in making management decisions. However, this does not mean that crop yields should not be maximized within a sustainable agriculture system. By maintaining flexibility of crop sequence within a rotation, a producer can make crop selection decisions to meet production goals, one of which may be to maximize yield. An overall recommendation based on this study is that crop yields are maximized when a grain crop follows soybean rather than following itself or another grain crop. A corn-soybean sequence produces the highest corn and soybean yields in wet years, but a grain sorghum-soybean sequence produces highest crop yield in dry or average years. Although an economic analysis might produce different conclusions, we have demonstrated the agronomic advantage of rotating row crops in wet, average, and dry years.

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The influence of conventional and compost fertilization on phosphorus use efficiency by broccoli in a phosphorus deficient soil

Marc A. Buchanan and Stephen R. Gliessman

Abstract. *Phosphorus (P) accumulation and use efficiency by broccoli (*Brassica oleraceae *var. italica) were observed in a field plot study comparing management with varying levels of conventional fertilizer, differing composted amendments, and a combination of inorganic Nitrogen (N) and compost sources. Total P accumulation and yield were highest in treatments incorporating solely compost or vermicompost applications of 30 tons ha^{-1}. Applications of N as ammonium sulfate caused significant soil acidification, which lowered yield and P uptake. Poor growth and yield were probably related to manganese toxicity effects on root extension and activity. These effects were partly ameliorated in treatments combining fertilizer N and compost sources. As a result, yield in plots receiving 75 kg N ha^{-1} as ammonium sulfate and 8.9 kg P ha^{-1} as compost was nearly identical to highest experimental yields. Phosphorus use efficiency was highest in this treatment incorporating fertilizer N and compost. Generally, P use efficiency tended to decline at the highest levels of fertilization. We propose that intensive organic matter management may be a good way to improve P use efficiency by vegetable crops.*

Key words: pure efficiency, compost, vermicompost, broccoli, soil acidification, P adsorption, manganese toxicity

Introduction

Phosphorus (P) fertilization (water-soluble forms) has been a critical input in high-yield agriculture. However, crop uptake efficiency of fertilizer P is generally low. Heavy P fertilization has often been adopted to compensate, not only for removal by the crop, but also for the varying P fixation and adsorption potentials by soils (Novais and Kamprath, 1978). Many soils used for the production of vegetables have accumulated high levels of residually available P (Peck and MacDonald, 1986). It might be assumed from the relatively few studies concerning nutrient use efficiency in vegetable cropping systems that this important component affecting efficient and sustained productivity has not been thoroughly examined.

Several studies suggest that organic sources of P can increase available and residually available P as effectively or more effectively than rock or soluble P sources (Sample et al., 1980; Meek et al., 1982; Swaider and Morse, 1984; Mishra and Bangar, 1986; Singh et al., 1987). The interaction of organic amendments and soil is relatively complex, and often the resultant influence on plant productivity cannot be solely explained by the nutrient content of the material. For soil P, much of this effect may be the result of: (1) increases in the organic P fraction (Azvedo and Stout, 1974); (2) increases in the size and turnover rate of the soil microbial P pool (Coleman et al., 1983); (3) increased hydrolysis of organic P compounds resulting from microbial phosphatase activity (Mishra and Bangar, 1986); and/or (4) organic anion competition for P sorption sites (Sample et al., 1980; Swaider and Morse, 1984).

Various organic wastes and composts may be incorporated into soils both as a disposal method and as a production amendment. The incorporation of stabilized wastes as compost can increase soil porosity, water-holding capacity, water infiltration, and cation exchange capacity, while decreasing surface crusting and bulk density (USDA, 1978). These effects may indirectly improve the ability of crop roots to gain access to and absorb soil P.

In this study, we applied inorganic and compost fertilizer, separately and in combination, to "Premium Crop" broccoli (*Brassica oleraceae* var. italica). The primary objective of our field study was to compare fertility management schemes in their effects on yield, total plant dry matter, soil chemical properties, nitrogen (N) and P accumulation, and distribution in the plant. We will report on soil inorganic N fluxes, crop N accumulation, and N use efficiency elsewhere (Buchanan and Gliessman, submitted). In this paper, we report fertilization effects on yield, crop P accumulation, P distribution in crop parts, selected soil chemical properties, and P use efficiency.

Materials and methods

We conducted field investigations at the University of California-Santa Cruz

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Agroecology Farm Facility. Studies were conducted on an Elkhorn sandy loam soil (fine loamy, mixed, thermic, Pachic Argixeferoll). This soil type has been characterized as P deficient (Arkley, 1967). The area used for the experiment had been a grazed grassland for at least 50 years. Soil chemical and physical properties did not vary significantly within this area. The physical configuration of the site did not allow for blocking of the treatment replicates. Therefore, we used a completely randomized design with treatments replicated three times in individual plot sizes of 4 x 5 m. Chemical analyses of selected soil properties are presented in Table 1.

Table 1. Selected elemental analysis of Elkhorn soil at 0-20cm depth following initial tillage.*

pH	Org. C (%)	Total-N	Inorg-N	Total-P	Avail-P	CEC**	Avail-Ca
		(ppm)				cmol	(ppm)
5.7	1.74	1280	12.4	419	2.7	15.13	1557

* Mean values of 40 samples.
** Measured by NH_4OAc saturation.

Treatments included: check (CK); ammonium sulfate at 75, 150, and 300 kg N ha^{-1} with 50 kg P ha^{-1} as superphosphate (N1,N2,N3); compost at 3.0, 7.5, and 30 Mg ha^{-1} (C1,C2,C3); compost at 3.0 Mg ha^{-1} with ammonium sulfate at 75, 150, 300 kg N ha^{-1} (CN1,-CN2,CN3); and vermicompost at 3.0, 7.5, and 30 Mg ha^{-1} (V1,V2,V3). The compost and vermicompost treatments were at rates typical for disposal or supply of plant nutrients. Ammonium sulfate was used as the fertilizer N source because this has been a common form used in vegetable production in the region.

Two compost batches, produced by thermophillic decomposition, were derived from a mixture of spent mushroom bedding, horse manure, bell bean, and hay residues. These composts were produced in 35-40 days in windrows that were completely remixed weekly and allowed to reach a maximum internal temperature of approximately 65°C. The vermicompost was produced in stationary, non-heating windrows primarily via the feeding activities of the earthworm, *Eisenia foetida*. Chemical analyses of the composts are presented in Table 2.

The grass root biomass in the experimental area was sampled and estimated, since it represented an additional source of labile N and P. Following primary tillage to approximately a 30 cm depth, the root mass was sampled with a monolith excavation method (Bohm, 1979). Soil was gently washed from the roots by the use of a fine stream of water passed through a series of sieves (2.0 mm to 500 mm). The biomass was estimated to be 5,634 kg ha^{-1}, with 48.3 and 4.2 kg ha^{-1} of total N and P, respectively. Following rotovation, the plots were set and initial soil samples (10 cores/plot, combined) were taken from the 0-20 cm depth interval. Soil was sampled at 2, 4, and 8 weeks following broccoli transplanting from the 0-20 cm depth (10 cores/plot, combined) for determination of pH. Extractable P was measured only on the final samples taken at crop harvest.

The three applications represent a range from a minimum to an excess of the crop's N requirement. The inorganic N and compost amendments were applied as split applications, the first comprising 67 percent of the total application. All materials were broadcast and incorporated to a 5-8 cm depth. After a 4-week bare fallow, allowing some decomposition of existing grass root biomass, and following seedling transplanting, the remaining material and superphosphate P were incorporated similarly. Soil in the experimental unit was not limed to normal recommended levels (1.5-2.0 tons ha^{-1}) to allow us to observe the influence of the organic amendments on soil pH and pH buffering

Broccoli seedlings were transplanted at 0.5 m spacing in the 4 x 5 m plots. Weekly irrigations (approx. 30 mm) were supplied by overhead sprinklers during crop development and maturation. At four weeks following transplanting, a newly expanded leaf was collected from each of ten plants per plot, with subsequent analysis for total P. At harvest (eight weeks following transplanting) ten mature plants were uprooted from each plot for determination of total plant dry matter and fresh and dry weight yields. Flower heads were cut and weighed fresh; later, the plants were further divided into the root, stem-stalk, and leaf components. All plant parts were weighed fresh, then dried and reweighed for dry matter determinations. The dried material was ground in a Wiley Mill with a 1 mm mesh screen and then analyzed for total P and other elements.

Soil chemical analysis

Fresh field soil and compost samples were analyzed for pH in saturated pastes with a glass electrode and a double-junction reference electrode. Organic carbon was determined by the Walkley-Black wet combustion method (Nelson and Sommers, 1982). A modified Walkley-Black method was utilized on air-dried compost samples. Total P in soils, com-

Table 2. Selected chemical analysis of three composts* incorporated into soil prior to transplanting.

Properties	Samples		
	compost#1	compost#2	vermicompost**
pH	7.45	6.85	7.50
Org. C (%)	12.8	21.36	9.03
Org. N (%)	0.80	1.55	0.75
NH_4-N (ppm)	2.8	4.3	1.5
No_3-N (ppm)	12.7	23.6	91.0
Total P (%)	0.30	0.25	0.47
Avail. P (ppm)	n.d.	6.4	11.1
Total K (%)	1.87	1.53	0.89
Total Ca (%)	1.93	2.38	2.57

* Composts produced from mushroom bedding, horse manure, crop residues.
** Vermicompost produced from horse manure.

posts, and plant tissues was determined after micro-Kjeldahl digestion by methods for the Technicon Autoanalyzer (Bremner and Mulvaney, 1982). Available P was determined by extraction in a 0.001 percent HCl and 0.001 percent H_2SO_4 solution with P determinations made with a molybdate-ascorbic acid procedure (Olsen and Sommers, 1982).

The P adsorption potential of soils from selected treatments was estimated to determine the relationships among extractable P, soil pH, organic carbon, and adsorption, as influenced by selected field treatments. The P adsorption potential determined here estimates the ability of the soil solid phase to remove orthophosphate P from solution. It has been used to estimate P fertilization requirements when soils appear to have a large fixation capacity (Fox and Kamprath, 1970).

Soil samples (combined subsamples) from the CK, N3, C3, CN1, and V3 plots were used in this study (Table 3). We weighed triplicate 2.5 g samples from each treatment into 125 ml flasks. The flasks were stoppered and the soil was then shaken with 25 ml of a 0.01N NaCl solution containing varying amounts of inorganic P as K_2HPO_4 (2,5,10,20,50 and 100 ug ml^{-1}) for 72 hours at 20° C (Griffin, 1982). After this incubation, the resulting filtrate was analyzed for P with the molybdate-ascorbic acid method (Olsen and Sommers, 1982). The amount of P adsorbed from the equilibrating solution was plotted against the P remaining in solution to produce individual adsorption isotherms for each treatment and soil (Woodruff and Kamprath, 1965; Griffin, 1982).

Statistical analyses were performed by use of the Statistical Analysis System for

Table 3. Effects of soil fertility treatments on available P at crop harvest 12 weeks after incorporation.

Treatment	Available soil P [ug g^{-1}]	
	Pre-crop	Crop harvest
CK	3.0	2.4
N1	2.7	4.6*
N2	2.9	1.8
N3	3.1	1.0
CN1	3.1	4.3*
CN2	3.0	2.8
CN3	2.9	3.6
C1	3.0	4.2*
C2	2.9	7.1*
C3	2.9	8.7*
V1	2.8	5.5*
V2	2.6	6.5*
V3	3.0	22.4*
LSD	0.6	1.5

* Means within columns significantly different from control ($p < .01$).

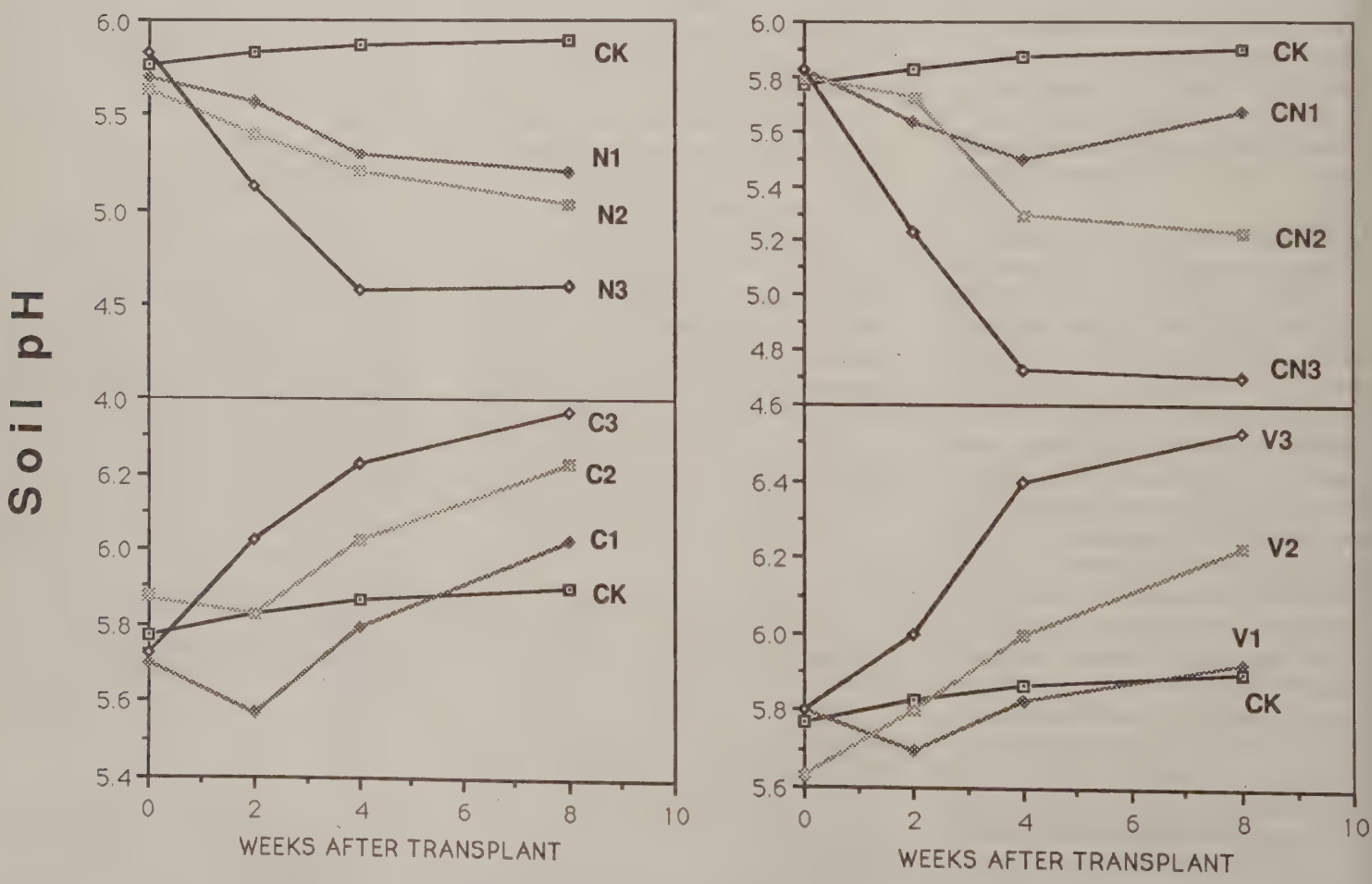

Figure 1. Changes in soil pH during the cropping period (weeks) as affected by soil fertilization treatments.

the completely randomized design (Hellwin and Council, 1979). Where ANOVA indicated significant treatment effects ($p < 0.01$), LSD values were computed to indicate differences among treatments.

Results

Soil pH effects and extractable P

One of the most important treatment effects was on soil pH, with significant reductions occurring in response to the increased incorporation of ammonium sulfate (Figure 1). We had not anticipated the low pH buffering capacity of this soil. The sharp decrease in pH in the N treatments certainly had a large negative impact on plant growth and yield. All treatments incorporating ammonium sulfate showed significantly increased acidity in comparison to the check, with the exception of the CN1 treatment. Soil pH changes associated with the control, C1, CN1, and V1 treatments did not differ at harvest. The compost and vermicompost treatments increased soil pH with increasing applications. It is apparent from the plots of pH change over time that the incorporation of compost with the inorganic N temporarily buffered soil pH (Figure 1).

Extractable soil P data at crop harvest further demonstrated the effects of the treatments (Table 3). While over the entire experiment this measure of soil P did not correlate with yield, it did show significant correlation with application level in the C and V treatments ($r=0.89$ and $r=0.91$, respectively). No correlation was found in any treatment incorporating ammonium sulfate. Extractable P determined at harvest was lower than pre-cropping values in the N and CN treatments. No clear relationship was found between extractable P and soil pH

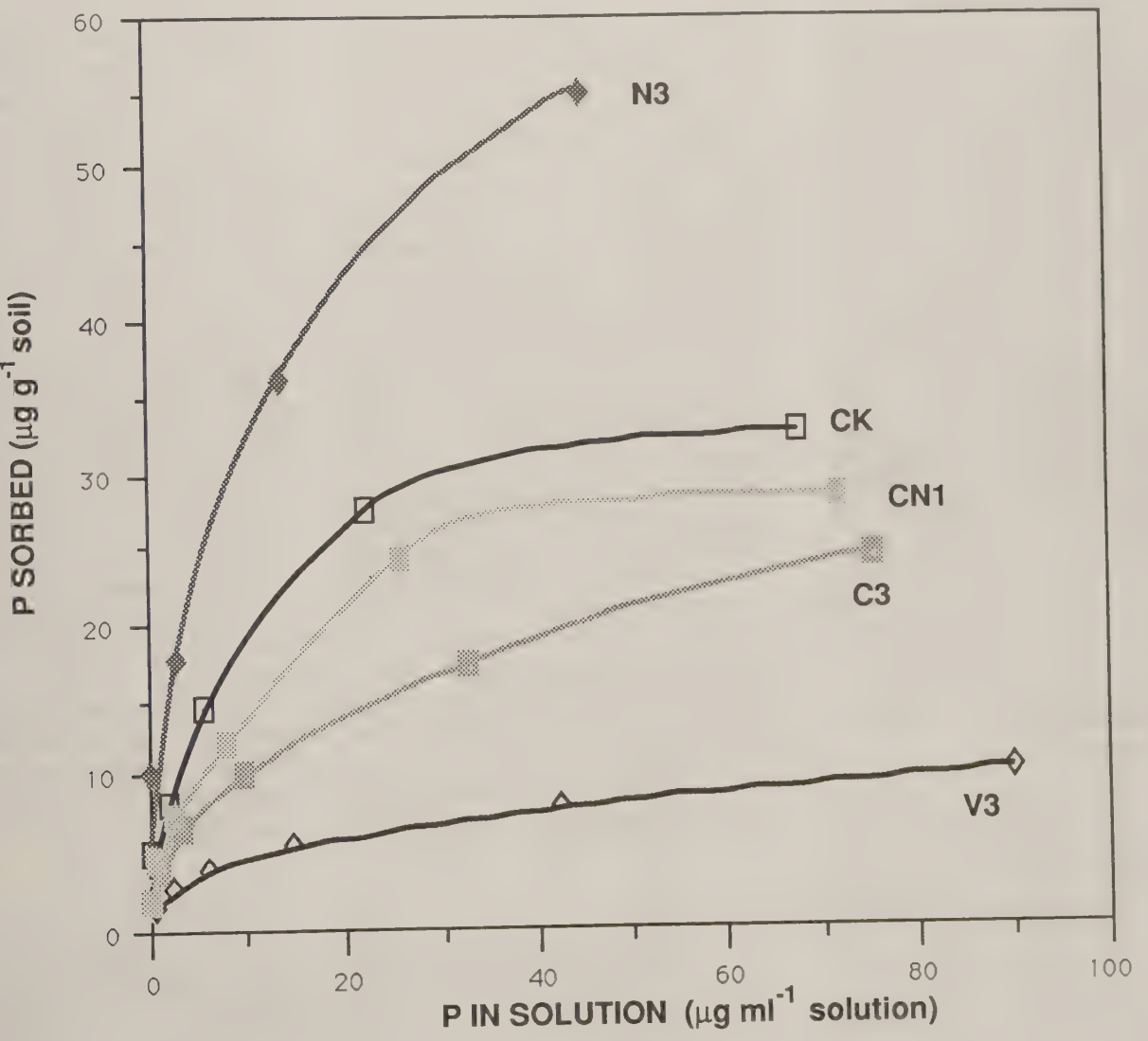

Figure 2. P adsorption isotherms for selected samples following a 72 hour equilibration with solutions containing 2,5,10,20,50, and 100 ug P ml^{-1} (n=3)

measured at harvest across the entire experiment.

Phosphorus adsorption

The 72-hour equilibration demonstrated the potential of a rapid adsorption phase only. These data showed the potential of selected treatment soils (CK, N3, CN1, C3, and V3), sampled after crop harvest, to remove orthophosphate P from solution (Figure 2). Sorption of P varied significantly among the soils from the five treatments. The curves show differences in P sorption potential with the change in slopes at differing equilibrium P concentrations. The N3 soil appeared to have the greatest potential for P sorption, followed by CK, CN1, C3, and V3 soils. The flattening of any curve suggests a significant saturation of sorption capacity. The slope of the N3 soil has not begun to decrease, which suggests that significant quantities of P would continue to be removed from solution at higher equilibrium P concentrations.

We also considered correlation of P adsorption with soil pH, organic carbon, and extractable P. The total amount of P sorbed in each soil showed significant negative linear correlations with pH and available P (R^2=0.94 and R^2=0.85, respectively). Multiple regression of pH and available P yielded a highly significant relationship (R^2=0.99). There was no relationship between P sorbed and organic carbon. While crop dry weight yield showed no correlation with P sorbed over all five soils, there was a significant negative relationship when the CK treatment (no P) was eliminated (r=-0.94).

Crop response and P accumulation

The broccoli crop responded differently to the field treatments. Fresh weight yields were greatest in the V3, C3, and CN1 treatments, and all plants had marketable heads (Table 4). The crop in the N treatments did not respond positively to the increasing applications of inorganic N and did not produce market quality heads. The CN treatments exhibited an irregular yield response with increased inorganic N. While all of the CN treatments had a positive response in comparison to the check treatment, the CN2 and CN3 yields were significantly lower than those in the CN1 treatment. Conversely, the treatments with compost or vermicompost alone had caused consistent yield increases. Dry weight yield paralleled the fresh weight yield, although the heads from the N and CN treatments tended to have a lower moisture content (unpublished data). Across all experimental treatments, yield was significantly related to total plant dry matter production (r=0.88).

The data for total above-ground dry matter production and P accumulation are presented in Table 4. Analysis of data for total plant dry matter, yield, and P accumulation indicated that P was a critical limiting factor for growth. Correlation of yield and total dry matter against total plant P accumulation (dry matter times P concentration) in all treatments revealed highly significant relationships (r=0.91 and r=0.90, respectively). Correlation of yield against P accumulation by the flower head was also highly significant (r=0.97), as was the relationship of yield against P concentration in the flower head (r=0.88). Linear regression models for these comparisons and the relationship between yield and root P concentration are given in Table 5.

Crop P accumulation increased with increasing P supply from compost sources. The greatest accumulation occurred in plants from the V3 treatment, while the lowest occurred in the N treatments (Table 3). Total P accumulation was lowest in the N treatments but was similar to that of plants in the CK, C1, and CN3 treatments. The similarity between the N treatments and the check suggests that the P supplied as superphosphate was not utilized by the crops. The differences among plants from the N and CN treatments were striking and suggest that the compost maintained more favorable soil conditions for root extension and absorption of P.

At four weeks following transplanting, the leaves from plants of the C3, V3, and CN1 treatment had the highest P

Table 4. Fresh weight of heads, total plant dry matter, and P accumulation as influenced by soil fertilization management.

Treatment	P applied	Heads (fresh wt.)	Total plant (dry wt.)	P content
	----------kg ha^{-1}----------			
CK	0.0	1248	2226	3.3
N1	50.0	1492	1651	2.6
N2	50.0	1794	1862	2.4
N3	50.0	1092	1719	2.3
C1	8.9	2324*	2870*	3.8
C2	22.3	4290*	3936*	9.4*
C3	89.4	7443*	5080*	14.1*
CN1	8.9	6468*	4137*	9.2*
CN2	8.9	3032*	3393*	6.7*
CN3	8.9	3572*	3104*	4.4
V1	14.1	3107*	3016*	3.9
V2	35.2	4648*	3894*	10.5*
V3	141.0	8190*	6201*	22.8*
	LSD	813	599	0.81

* Means within columns significantly different from control at p<.01.

Table 5. Linear regression models of dry matter yields of broccoli versus phosphorus uptake parameters.

Yield × Total P uptake	y = 459.16x + 38.7	(R^2 = .78)**
Yield × Head P uptake	y = 1251.23x + 30.6	(R^2 = .95)**
Yield × Head P conc.	y = .057x − 124.79	(R^2 = .79)**
Yield × Root P conc.	y = .099x − 17.07	(R^2 = .57)*

* p<.01.
** p<.001.

concentrations (unpublished data). None of the N treatments was different from the check, but the leaves of the CN treatments had significantly higher P concentrations. Over all treatments, yield was significantly related to four week leaf P concentration ($r=0.89$). At harvest, the leaves from CN1 treatments showed the greatest proportional decrease in P concentration from the four-week sampling. This suggests that retranslocation of P may have been high or that it simply may be the result of a "dilution" effect.

At harvest, differences in P concentration of head, leaf, and stem parts between the check and N treatment plants were not significant (Table 6). The crop parts from the CN treatments were generally higher in P than the N treatments. However, with increasing inorganic N supply, P content decreased in all crop parts. The crop parts from the compost and vermicompost treatments had increasing P concentrations with increased application levels.

Table 6. P concentrations in broccoli crop parts at harvest as influenced by soil fertility management.

Treatments	P concentration [ug g^{-1}]			
	Head	Leaves	Stems	Roots
CK	0.33	0.18	0.12	0.07
N1	0.34	0.14	0.12	0.13*
N2	0.30	0.13	0.10	0.11*
N3	0.38	0.15	0.11	0.08
CN1	0.52	0.20	0.15	0.13*
CN2	0.37	0.21	0.18	0.11*
CN3	0.34	0.21	0.10	0.09
C1	0.32	0.17	0.11	0.11*
C2	0.40	0.19	0.23*	0.13*
C3	0.61	0.40*	0.24*	0.18*
V1	nd**	0.27*	0.15	0.13*
V2	0.53	0.33*	0.21*	0.17*
V3	0.66	0.42*	0.32*	0.30*
LSD	0.06	0.07	0.08	0.03

* Means within a column significantly different from control ($p<.01$).
** Head sample lost.

Phosphorus use efficiency

We described P use efficiency with three quantitative relationships. The first calculation, which we define as fertilizer use efficiency (FU), relates P accumulation by the crop to the amount incorporated into soil:

$$FU = \frac{P_{af} - P_{ac}}{P_{ap}}$$

where: P_{af} is the P accumulation by fertilized crop

P_{ac} is the P accumulation by check crop

P_{ap} is the total P applied to soil

The physiological efficiency (PE) relates yield to plant P accumulation (Novoa and Loomis, 1981; Harmsen, 1984):

$$PE = \frac{Y}{P_{up}}$$

where: Y is the dry weight yield

P_{up} is total plant P accumulation

The agronomic efficiency (AE) consists of two components, the physiological efficiency and fertilizer use efficiency:

$AE = PE \times FU$

These various calculations are presented in Table 7. It can be argued that the lack of data for root biomass and nutrient accumulation results in values lower than actual ones. However, determination of this parameter is rarely reported. In our analyses we have also ignored nutrient accumulation by roots and the possibility of differences between the treatments. In general, P use efficiency by any measure was relatively low, with some notable exceptions. The N treatments resulted in decreasing physiological efficiency with increased applications in all treatments.

The fertilization efficiency tended to decrease at higher applications of inorganic N in the CN treatments and with compost in the C and V treatments. The CN1 treatment stands out consistently as the most efficient in all analyses. Most significant is the comparison of the CN1 treatment with the N1 treatment, which suggests that there was a significant positive effect due to the incorporation of stabilized organic matter. This effect is also seen, though to a lesser degree, in the comparison of any of the CN treatments with the N treatments.

Calculations for treatments incorporating composts represent crop recovery from the initial soluble P in the materials and from the P released from organic/inorganic fractions following soil incorporation. Given the methods employed here, we are not able to assess the specific contributions of any of the various fractions of P assumed to be present in the composts.

Table 7. Phosphorus use efficiency calculated as fertilizer use efficiency (FU), physiological efficiency (PE), and agronomic efficiency (AE) due to fertilization treatments.

Treatments	P applied (kg ha^{-1})	FU	PE	AE
CK	—	—	46.36	—
N1	50.0	<0*	95.00	<0
N2	50.0	<0	101.67	<0
N3	50.0	<0	69.13	<0
C1	8.9	.056	100.00	5.6
C2	22.3	.274	49.79	13.6
C3	89.4	.120	65.46	7.9
NC1	8.9	.664	91.85	61.0
NC2	8.9	.382	57.76	22.1
NC3	8.9	.126	100.45	12.7
V1	14.1	n.d**	n.d	n.d.
V2	35.2	.205	54.76	11.2
V3	141.0	.138	40.61	5.6

* Could not be calculated as P uptake was less than CK.
** Head sample lost so that the calculation could not be made.

Discussion

It is apparent from the data for yield, total plant dry matter, and P accumulation that the superphosphate P applied to soils in the N treatments was not effectively utilized by the crop. This obviously counters most observations of crop response to N and P fertilization. This result is no doubt related to ammonium sulfate's effect on soil pH and, perhaps, to its concurrent negative effects on crop roots. In addition, we did not match total P applications across all treatments, as the primary objective of the study was to compare N fertility management schemes. Thus, we have confounded any true agronomic comparison of the inorganic fertilizer treatments with compost treatments. However, our study did allow for observations on the effects of organic matter additions.

In addition to the P supplied, the slightly alkaline pH of the composts probably contributed to the observed buffering and increases in pH. This is evident in the plots showing pH change over time (Figure 1). From the data for soil pH in the CN1 plots, we conclude that the buffering property associated with compost incorporation directly related to the positive yield and P accumulation response. It appears that the buffering of soil pH at 5.7 created conditions more favorable for root extension, P absorption, and dry matter production. We speculate that this is also true for all treatments that maintained a soil pH identical to the check soils or increased the pH towards neutrality.

This pH buffering effect, combined with increasing P application, would partially explain the increased positive effects of compost and vermicompost incorporation on yield, plant dry matter, and P accumulation. Phosphorus availability was probably positively influenced by the small labile pool of P in the decomposing root biomass. Comparisons of extractable soil P measured at crop harvest, and its lack of relationship to yield, confirms that factors other than the amount of P incorporated influenced P accumulation, yield, and total dry matter production.

For example, there are other characteristics of vermicomposts that should be considered. It is generally acknowledged that earthworm casts are higher in available nitrogen, phosphorus, calcium, and magnesium than the initial substrates that worms feed on (Vleeschauwer and Lal, 1981; Satchell, 1983). Alkaline phosphatases, which are associated with transmembrane absorption, have been found in significantly active concentration in the gut of *Eisenia foetida* (Van Gansen, 1962). The casts are thus higher in labile P; and, in addition, significant amounts of phosphatases are voided in the casts (Satchell and Martin, 1984). Further, it appears that the numbers and activity of soil microorganisms with acid phosphatase activities increases near the casts (Satchell and Martin, 1984; Satchell et al., 1984). These specific effects could have great bearing on P availability in soils following incorporation.

The Elkhorn sandy loam has been described as a P deficient soil, the characterization being based on a quick field test for soluble P (Arkley, 1967). The native soil is characteristically acid (pH = 5.3-5.8), averaging about 62 percent base saturation, with effectively no free carbonates in spite of the occasional limestone fragments eroded and transported from higher slopes (unpublished data). The labile iron (Fe) and manganese (Mn) contents are high (20-25ppm and 50-65ppm, respectively), and soil peds are characteristically coated with Fe and Mn compounds.

Rapid adsorption of applied P can occur in soils with high content of Fe, Al, and Mn oxides (Truog, 1948; Wild, 1950; Fried and Shapiro, 1956; Bache and Williams, 1971; Sample et al., 1980). A rapid adsorption phase is followed by a slower precipitation phase which increases the insolubility of newly formed complexes (Sample et al., 1980; Sposito, 1984). The adsorption capacity increases with decreases in soil pH as more adsorption surfaces become active. Therefore, in the Elkhorn soil, the availability of P may be controlled by adsorption on Fe and Mn coated surfaces and the increased insolubility of newly formed phosphate compounds with time.

From the data for P adsorption potential, it appears that treatment effects on P sorption could have had some negative impact on the availability of P. The data for the N3 treatment suggest that much of the P applied as superphosphate could have been quickly removed from soil solution through adsorption and/or precipitation reactions. As the yield and P accumulation data for all of the N treatments are similar, we can speculate that P adsorption was increased in all of these treatment soils. The P adsorption curves for CN1, C3, and V3 soils suggest that P adsorption exerted less control over soil solution P.

A more favorable environment for release of P from the labile organic fraction and release of bound inorganic P during resumed decomposition of these materials probably increased the efficiency of P supply from compost sources. Indirectly, organic matter can complex iron, aluminum, and manganese between dissociated carboxyl and phenolic functional groups, thereby reducing P adsorption or precipitation potential (Dalton et al., 1952; Earl et al., 1979; Swaider and Morse, 1984). Sufficient organic matter additions with concurrent increases in soil pH may reduce the bonding energy of adsorption (Sample et al., 1980). This would likely be very important on high adsorption soils with low initial available P.

An additional factor was probably involved in the lowered dry matter production in the N and higher CN treatments. After five weeks of growth in the field, the plants in the increasingly acidic soils were visibly stunted. The older leaves occasionally showed interveinal chlorosis and in time cupped upward with necrotic margins. These symptoms were noted in Brussels sprouts on Elkhorn soils in San Mateo County in the late 1950's (Lingle and Sciaroni, 1959). Decreased soil pH (<5.0) due to repeated applications of nitrogenous fertilizers, particularly ammonium sulfate, caused increasing manganese toxicity in crops on these coastal soils (Lingle and Wright, 1961).

Increased soluble concentrations of Mn^{+2} and aluminum (Al^{+3}) are known to occur in highly acidic or highly reducing soil environments. From the symptoms observed, we speculate that there was a degree of manganese toxicity acting to reduce the crop's ability to absorb P. Although the possibility of Al toxicity cannot be ruled out, our review of the

literature suggests that manganese toxicity would be the dominant nutritional disorder in the Elkhorn soil series. Nonetheless, any excessive quantities of Mn or Al in the soil solution would likely have decreased root growth, as well as uptake and translocation of P.

The data for leaf and stem P for the CN1 treatment at harvest suggest that retranslocation of P was related to the high physiological efficiency of this treatment. This speculation is supported by data for leaf P concentration on samples taken four weeks after transplanting. The higher application levels of compost and vermicompost treatments may have allowed "luxury" absorption of P. The high fertilizer use efficiency also suggests that the CN1 treatment resulted in nearly optimal soil conditions for root absorption of P.

Under favorable conditions, where P availability is adequate, much of the P in leaves and stems is retranslocated to the developing reproductive sink. Williams (1948) with oats and Vendekamp et al. (1986) with maize observed the variation in P distribution under P deficient, adequate, and high availability conditions. Phosphorus deficient plants retained a large portion of the total accumulation in roots, stems, and leaves, with little retranslocation to the grain heads. With an adequate supply, most of the P was initially in stems and leaves, and significant retranslocation reduced their P content during seed maturity. The data for the CN1 treatment is consistent with this observation. At high P supply in the cited studies, root, stem, and leaf accumulation were large, with a smaller percentage of the total exported to the maturing seeds. Thus, we conclude that the high P content of crop parts in higher compost treatments is due to excess absorption related to high P availability, while P supply in the CN1 treatment was optimal.

Conclusions

Our study demonstrates that the accumulation and distribution of P in broccoli can be largely affected by fertilization effects on the soil environment. Organic matter management with slightly alkaline composts may partially substitute for soil pH management, while providing crop nutrients. Increasing applications of the composts tended to increase yield and P accumulation, while resulting in lowered P use efficiency. A fertilization scheme incorporating split applications of inorganic N with compost clearly increased yield, P accumulation, and P use efficiency over other treatments. The incorporation of compost appears to have prevented the rapid soil acidification that occurred in treatments incorporating only ammonium sulfate and superphosphate.

Given the low pH buffering capacity of this soil, the additions of inorganic N as $(NH_4)_z SO_4$ resulted in conditions that probably caused manganese and possibly aluminum toxicity in crop plants. Thus, comparison of P use efficiency in these treatments with those of compost treatments is difficult. The addition of inorganic N also increased the P adsorption potential of the soil, although it may not have directly affected soil P availability. It is more likely that the addition of the composts caused important changes in soil chemical, physical, and/or microbiological properties that improved the environment for root extension and P absorption. Even where agricultural lime prevents a toxicity condition, we believe that organic matter additions of this type with inorganic N or P fertilizer may enhance P use efficiency compared to fertilization with residually acidic N fertilizer and inorganic P.

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LETTERS

Outlines, complexity, and breadth of sustainability

Having been to many agricultural gatherings where the topic of "sustainable agriculture" was addressed, I have an impression that the mainstream agriculture establishment still believes all is well and that we can fix agriculture's problems by simply trying out a few reduced chemical experiments, a few comparisons with conventional methods, and that is "sustainable agriculture." The sustainability of agriculture thus has been reduced to the question of chemical use.

Reduction and elimination of petrochemicals is a very important aspect of a healthy agriculture, and we do need to search for agronomic practices that enhance soil life. However, even if all farms become chemical free, we will be far from a sustainable agriculture unless we seriously address the following basic questions, concerns, and goals:

Renewable energy. Currently, we are converting barrels of oil to bushels of grain; our modern agriculture is running entirely on rapidly depleting oil and gas, and our so-called "safe food supply" is extremely vulnerable. No agriculture can be sustained unless it runs on renewable energy. What are we doing in our research to address and seek ways of kicking the petrofarming habits? What are we doing to promote a fresh, locally grown food economy, to invest in the local community, as well as to avoid processing, packaging, and transportation?

Rural communities. More than 200,000 farms went bankrupt in the 1980's alone. By almost any measure, our rural communities are declining. Are the land-grant universities, the USDA, and state departments of agriculture building and revitalizing communities? Are we addressing the root causes of rural decline? Those of us who are seeking sustainability in agriculture see agriculture and rural communities rooted in one another and inseparable. We must invest in and build on our rural heritage.

Soil and water conservation. Neither agriculture nor people can survive if we continue to waste soil and pollute our water. We have more soil erosion now than we did during the Dust Bowl era. How can we reverse this trend?

Health questions. We, the public, are concerned about pesticide residue on our food, chemicals in our drinking water, antibiotics and hormones in our food, and risks to the farmer. The connection between our health and our agriculture is ignored entirely by experts who, with their usual self-assured tone, tell us all is safe and that, since there is no proof it is unsafe, do not worry. Since people's lives and the health of the biosphere are at stake, why shouldn't the burden of proof that our food is safe rest on those who claim so?

Agricultural policies. In order for agriculture to be economically viable, environmentally sound, and socially just, we need local, national, and international policies that help rather than work against these goals. Our universities should be a debating ground for these policies. How are agricultural policies affecting the people and agriculture?

True economics. All things that the "economy" depends on come from the Earth. Our current economic thinking does not take the Earth and the future generations into account. In a true economy, conservation is always economical and degradation extremely costly. We need to transform our fake economics so that it will truly reflect our dealings with the Earth.

Education, research, and extension. A shift towards a sustainable agriculture necessarily requires a fundamental change in our short-term, departmentalized research and teaching. It also requires direct farmer-researcher, farmer-farmer, and farmer-student exchange of ideas and practices. In order to make the university research more relevant to real problems of agriculture, colleges of agriculture must be mandated to run a farm successfully and profitably. That process can transform us and our efforts in education, research, and extension in unforeseen

ways.

Urban responsibility. The 98 percent of Americans who are urban residents cannot lead wasteful lifestyles with polluting industries and expect the farmers to run chemical-free farms and be stewards of the land. Urban generated pollution will continue to impact agriculture negatively. What are *we* doing in the cities to conserve energy, recycle, and prevent air and water pollution?

Multi-national corporations and rural communities. How are the multinational corporations affecting agriculture, people, rural communities, and the land in the U.S. and abroad? Can we have a healthy agriculture when a handful of corporations control the entire market in agriculture?

A land ethic. Our ethics prompt us to care for other individuals and the community; our ethics rule out doing things that harm the community. Aldo Leopold described a land ethic in *A Sand County Almanac*, "The land ethic simply enlarges the boundaries of the community to include soils, waters, plants, and animals, or collectively the land. That land is a community is the basic concept of ecology, but that land is to be loved and respected is an extension of ethics."

Generally, no concept of a land ethic seems to prevail among agriculturalists, universities, and our entire educational system. Aldo Leopold believed "conservation is getting nowhere because it is incompatible with our Abrahamic concept of land. We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect." What can we do to integrate a land ethic into our education, agriculture, and lives?

All of these concerns and questions must be central to our search towards a sustainable agriculture.

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BOOK REVIEWS

The Ecology of the Nitrogen Cycle. 1987. By Janet I. Sprent. Cambridge University Press, New York, New York. 151 pp. $39.50, cloth; $14.95 paper.

Janet Sprent has written a small volume which might have been entitled "The Nitrogen Cycle in a Nutshell." Despite its brevity (its 151 pages include references and an index), it is remarkably informative and comprehensive, containing 243 references to relevant research. The book is aimed at advanced undergraduates, early graduate students, and researchers in allied areas, particularly agronomy and ecology. It should be extremely useful to this group. It should also be of interest to the scientifically informed portion of the general public, especially those concerned with environmental issues.

The first part of the book, "General Features of the Nitrogen Cycle," gives background information about the nitrogen cycle. This section includes a description of the energetics and biochemical pathways of the major reactions of the nitrogen cycle, both biologic and abiologic. A discussion of the interrelation between the nitrogen cycle and other elemental cycles is included. The central importance of the interaction between the carbon and nitrogen cycles is appropriately emphasized. Past and present constraints on the nitrogen cycle and environmental effects on nitrogen transformations are also discussed.

Because of its brevity, the first section of the book may strike some readers as densely written. The information in the tables and figures is correct, but the reasons may not be obvious. Readers who want to go beyond taking the author's word for the accuracy of the material will often have to consult the references she cites to find the omitted explanations.

The general first section of the book provides both the information needed for and the point of view taken in the second section, which consists of case histories from particular environments, including arid and semi-arid ecosystems, tundra, forests, peat soils, areas subject to flooding, aquatic ecosystems, agricultural areas, and forests. A description of the effect of burning fossil fuels on the nitrogen cycle is included.

This book is well written by an outstanding authority in the field and is recommended both to readers who are tangentially interested in the operation of the nitrogen cycle and as an introduction for readers who are interested in studying the nitrogen cycle in greater depth.--*Georgia Shearer, Department of Biology, Washington University, St. Louis, MO.*

LETTERS TO THE EDITOR INVITED

The AJAA welcomes letters, short or long, commenting on articles in this journal or sharing ideas likely to be of interest to other AJAA readers. Since our space is limited, we do reserve the right not to publish all letters or, at times, to publish only excerpts from them. To take part in this exchange of ideas, write to: Editor, AJAA, 9200 Edmonston Road, Suite 117, Greenbelt, MD 20770.

Seventh annual symposium held March 6

"Learning From Each Other: New Models for Sustainable Agriculture Research and Information," was the topic for the seventh annual Institute symposium held in Washington, DC, on March 6, 1990. Keynote speaker Roland Bunch told participants that active farmers can multiply many times over the extent of research in sustainable agriculture. Bunch is the Central American Area Representative for World Neighbors, Inc.

Additional speakers included Gordon Watkins, organic farmer from Parthenon, Arkansas; Charles Francis, University of Nebraska Extension Specialist; Robert Miller, Dean at the University of Rhode Island; Richard Thompson, Iowa farmer and past president of the Practical Farmers of Iowa; John Gardner, Director of the Carrington Research Extension Center at North Dakota State University; Kay Thornley, farmer from Davenport, California; William Lockeretz of Tufts University; Myron Johnsrud, Administrator of the Extension Service; and Richard Sauer, President of the National 4-H Council. William Liebhardt of the University of California, Michael Heller of the Chesapeake Bay Foundation's Clagett Farm, and Jerry DeWitt of Iowa State University moderated panels. Farmers Jim Bender of Nebraska and Ward Sinclair of Pennsylvania were respondents to the final panel discussion.

Papers from the symposium will be published in a forthcoming issue of the *AJAA*.

Mrs. Jean Douglas honored by IAA

Mrs. Jean Wallace Douglas, former President of the IAA Board of Directors, was honored at a special reception held on April 23, 1990, at the home of Board Director Robert Blake in Washington, DC. A certificate naming Mrs. Douglas Lifetime Honorary President was presented by Executive Director Garth Youngberg. "There would not be an Institute today had it not been for your thoughtfulness, concern, and generosity," said Board President Jerald DeWitt in his letter of recognition.

Francis, King co-editors of sustainable agriculture book

Charles A. Francis and Larry D. King, members of the *AJAA* Editorial Board, are co-editors of *Sustainable Agriculture in Temperate Zones*, published in 1990 by John Wiley and Sons. Cornelia Butler Flora of Virginia Polytechnic Institute and State University is the third editor. Three other *AJAA* Editorial Board members are represented in the book: Tom Edens, John Doran, and J. Patrick Madden. *AJAA* Technical Editor William Lockeretz is also the author of a chapter, and IAA Executive Director Garth Youngberg co-authored a chapter with Charles Francis. The book "reviews the current thinking about the philosophy of sustaining agriculture into the future," the editors say in their preface.

Otto Doering of Purdue is Co-Chair of 1991 symposium

Otto Doering, Professor of Agricultural Economics at Purdue University, who has also been a 1990 visiting scholar at the USDA Economic Research Service, will join IAA Executive Director Garth Youngberg as Co-Chair of the Planning Committee for the 1991 IAA symposium. The symposium, scheduled for March 6, 1991, will focus on the true costs of food, including environmental and health factors.

"All societies pay for food, both directly at the consumer level, and indirectly, through government," Doering says. "In addition, there may be costs to health, to the environment, or to the resource base that are mostly hidden from view. The focus of this conference will be on identifying these various costs and assessing their relative magnitudes. Citizens then will have the final say about how they want to pay for food and which costs they are willing to bear today."

IAA supports $50 million LISA budget for FY1991

The FY1991 USDA budget should expand funding for the Low-Input/Sustainable Agriculture Program (LISA) from $4.45 million to $50 million, IAA Executive Director Garth Youngberg said in April 1990 testimony to both House and Senate Agriculture Appropriations Subcommittees. The program has not only yielded research pointing to successful substitutions for farm chemicals, but fostered "a new model for cooperative research," he said.

A portion of new funds could create a matching grant program to build federal-state partnerships, Youngberg suggested. A smaller amount could be used to develop state-level handbooks and field guides that incorporate information on such practices as rotations, nutrient management, and biological pest management.

Because some pesticides now under review may be banned, increased funding for research in biological pest control is also essential, Youngberg told the appropriations committees. He suggested $5 million for accelerated research in biological controls. Youngberg also asked for $3 million in support of the ATTRA hotline information service located at Fayetteville, Arkansas.

Guide for authors

AJAA will publish original research on biological, physical, or social science aspects of alternative agriculture. We particularly welcome multi-disciplinary studies, but papers from a specific discipline also are invited. However, since AJAA readership is much broader than for a single-discipline journal, highly specialized terminology should be explained or avoided. The significance of a statement, or the reasoning behind a conclusion, may have to be spelled out more than in a more specialized journal. Research papers usually should be no longer than about 20 double-spaced pages.

Nomenclature and technical details

Research papers should use the International (SI, or metric) system throughout. Write out "liters". "Metric ton", although not strictly an accepted SI unit, can be used for data referring to "ordinary life," such as national crop output, as opposed to experimental data. Occasional use of common unit equivalents in parentheses is permitted, mainly for relatively exotic SI units.

The binominal or trinominal designation of a plant or animal species, and the cultivar where relevant, should be given in parentheses the first time the common name of the species is mentioned. Either name may be used thereafter. The same applies to names of chemicals that have both a common name and a chemical name. Do not use brand names except where the chemical is produced under a unique brand name. In those cases the brand name, identified as such, may be given the first time the chemical is mentioned. Nutrient applications should be given in elemental form (N,P,K). Oxide forms can be used in describing commercial fertilizers.

Title page

The title page should give the following information (all flush left): 1) title of the paper; 2) names of authors; 3) affiliation and office address of authors, and 4) acknowledgements, if any. See examples in this issue of AJAA.

Abstract

The abstract should be 200 to 400 words suitable for readers from a broad range of disciplines. It should avoid highly-specialized terminology that might be appropriate for a single discipline journal. Take particular care that the significance of the work is made clear, even to readers from a different field.

Reference list

References should be listed in alphabetical order by author's name, and by year for a particular author (with letters after the year if needed). If a sole author is also the lead author of papers with multiple authors, use the following order: single author (by year); two authors (alphabetically by second author's name); three or more authors (by year). Repeat the author's name for each reference. Use initials only for first and middle names. Give the names of all authors in the reference; never use "et al."

Use full names of journals, institutions, conferences, etc., except for extremely familiar abbreviations like "Dept." Remember that an abbreviation familiar to you may not be familiar to readers outside your field. If in doubt, write it out.

The reference list uses no quotation marks, italics, boldface, or underlining. Only the names of books and periodicals are in initial capitals. Names of papers, book chapters, pamphlets, and bulletins are not capitalized. Page numbers are written out in full (e.g., 1108-1123, not 1108-23). The volume is given if page numbers begin at 1 for each issue.

Citing references

Cite references in the text by last name and year, with chapter or page numbers if the reference is a book or lengthy report. For two authors, give both names. Do not use "et al." unless there are at least three authors.

Footnotes

AJAA does not use bibliographic or substantive footnotes. All bibliographic references should be at the end of the text. Instead of substantive footnotes, include the material in the main text or consider eliminating it.

Manuscript preparation

The entire manuscript, including abstract and references, should be typed on one side of standard-size paper, double spaced, with margins of at least one inch all around. Starting with the title page, label all pages in the upper righthand corner with the lead author's last name and the page number. Do not use hyphens unless the hyphen is part of the word. Do not underline anything except species names.

Follow the section headings style used in this AJAA issue. All headings are flush left, with no underlining or italics.

Tables should fit on one page, be numbered consecutively with Arabic numerals, and be on a separate sheet. Leave extra space to separate columns. Every figure and table should be mentioned at least once in the text.

Submission of manuscripts

Submit four high-quality copies to Editor, American Journal of Alternative Agriculture, Suite 117, 9200 Edmonston Road, Greenbelt, MD 20770. The cover letter should state that the manuscript is an original contribution that has not been published elsewhere in substantially the same form; that it is not currently under consideration elsewhere, and that permission has been obtained for any copyrighted material used.

How you can help support the scientific and educational needs of a sustainable agricultural system

A growing number of Americans have become concerned about the long-term sustainability of our food production system. Farmers and agricultural scientists are among those raising questions about the growing dependence of modern farming on nonrenewable resources, the depletion of our resource base through soil erosion, and heavy reliance on chemical fertilizers and pesticides. Continued heavy reliance on farm chemicals is questioned because they have become an expensive production input. Their widespread use also raises questions about human and animal health, food quality and safety, environmental quality, and the continued demise of the family farm.

Low-input alternative farming methods address these economic and environmental challenges. Alternative production systems point the way toward more profits, more individual choice, and long-term sustainability for our food system. More must be done to develop effective ways to make sure research, education, and information sources are readily available to farmers who want to adopt these techniques.

The Institute for Alternative Agriculture needs your help in meeting this challenge. We are a nonprofit tax-exempt research and education organization set up in 1983 to encourage and facilitate the adoption of low cost, resource conserving, and environmentally sound farming methods. We work directly with government agencies, colleges and universities, producer groups, and other institutions that provide research, education and information services to farmers.

The Institute also provides these services:

- *A resource to lawmakers and others who influence agricultural research, education, and information policy*
- *A voice for alternative agriculture in Washington*
- *A sponsor of research and education outreach programs*
- *A national clearinghouse for information on alternative agriculture*
- *A publisher of reliable scientific information on agricultural sustainability*

If you're interested in helping us, please contact our office at 9200 Edmonston Road, Greenbelt, MD 20770. The phone number is (301) 441-8777.

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